A SIMULATION TO EVALUATE JOINT MILITARY LOGISTICS IN A HUMANITARIAN ASSISTANCE ENVIRONMENT

THESIS

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Abstract

Currently, no capability exists to simulate and measure a Joint Task Force-Port Opening (JTF-PO) operation in a safe, cost-effective manner in order to predict cargo throughput based on the availability of resources. The purpose of this research is to create a decision model through the use of Arena® simulation software to provide United States Transportation Command (USTRANSCOM) decision makers the ability to predict cargo throughput under a Humanitarian Assistance/Disaster Response (HA/DR) scenario. The data used in the construction of this simulation was taken from the JTF-PO involvement in Operation UNIFIED RESPONSE, Port-au-Prince, Haiti 2010. This research uses a design of experiments approach to statistically plan and measure the throughput of cargo based on the adjustment of working and distribution maximum on ground (MOG) resources. The resulting simulation model provides decision makers the ability to allocate multiple JTF-PO resource quantities to determine potential bottlenecks in cargo throughput in order to plan for future operations.

To my lovely wife and our three boy. I would not have accomplished this milestone without your love and support. I share this accomplishment with you.

Acknowledgments

I would like to express appreciation to my advisor, Dr. Cunningham, for keeping me focused on the important things in my research and not letting me second guess myself. Also, I would like to thank my reader, Dr. Johnson, for providing me insight on the world of computer simulation. Furthermore, I thank the Center for Operational Analysis support team, for assisting me in getting over the hurdles of some of the advanced techniques of Arena® simulation. I am also indebted to the past and present men and women of the 621st Contingency Response Wing and 688th/689th Rapid Port Opening Elements for providing me the data needed to complete this research. Of those, I owe a special thanks to Maj Matt Jones, Lt Col John Krystyniak, and Maj Armando Kuppinger for providing explanations of the data and the process of the operation. Finally, and most importantly, I especially thank my wife for taking care of our three boys at home while I was away studying for countless hours. Without my family's love and support I would not have had the time to complete my research and graduate.

Ryan S. Fisher

Table of Contents

List of Figures

List of Tables

List of Equations

List of Acronyms

AAR	After Action Report
AC	Aircraft
AMC	Air Mobility Command
AMCIT	American Citizen
AMOG	Air Mobility Operations Group
APOD	Aerial Port Of Debarkation
C2	Command and Control
CC	Commander
CCDR	Component Commander
CHISQ	Chi Square
COA	Course Of Action
CONOPS	Concept Of Operations
CRG	Contingency Response Group
CRN	Common Random Numbers
DOE	Design Of Experiments
ETMSC	Enhanced Traffic Management System Counts
EXPO	Exponential
FAA	Federal Aviation Administration
FIFO	First-In First-Out
FN	Forward Node
GAMM	Gamma
GoH	Government of Haiti
HA/DR	Humanitarian Assistance/Disaster Response
HEMTT	Heavy Expanded Mobility Tactical Truck
HN	Host Nation
IOC	Initial Operating Capability
IQ	Investigative Question
ITV	In-Transit Visibility
JAT	Joint Assesment Team
JDDOC	Joint Deployment and Distribution Operations Center
JFAST	Joint Flow and Analysis System for Transportation
JP	Joint Publication
JRSO&I	Joint Reception Staging Onward Movement and Integration
JSOAC	Joint Special Operations Air Component
JTF-PO	Joint Task Force-Port Opening
KS	Komolgorov-Smirnoff
LHS	Load Handling System
LOGN	Lognormal
MHE	Material Handling Equipment

MOBSIM	Mobility Simulator
MOG	Maximum On Ground
MSR	Main Supply Route
MX	Maintenance
NA	Not Applicable
ND	Not Documented
RFID	Radio Frequency Identification
RPOE	Rapid Port Opening Element
RQ	Research Question
SDDC	Surface Deployment and Distribution Command
SME	Subject Matter Expert
SOW	Special Operations Wing
STONS	Short Tons
TOS	Time On Station
TPFDD	Time Phased Force Deployment Data
TRIA	Triangular
UN	United Nations
UNIF	Uniform
USAFE	United States Air Force Europe
USTRANSCOM	United States Transportation Command
WEIB	Weibull

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A DISCRETE-EVENT SIMULATION MODEL FOR EVALUATING JOINT TASK FORCE-PORT OPENING OPERATIONS IN A HUMANITARIAN ASSISTANCE/DISASTER RESPONSE SCENARIO

I. Introduction

Background

Expeditionary Air Force units designed to open airfields are not new to the military, but a rapidly deployable multi-modal and distribution concept is a young capability. Since World War II, the Air Force has slowly transitioned from massive war-fighting capability stationed all around the world to a light, lean, and lethal expeditionary capability designed to deploy to anywhere in the world.

During an overarching Air Force service restructure in 1997, numerous functions required to operate forward mobility locations were realigned under one command, Air Mobility Command. The Air Mobility Operations Group (AMOG) was formed to establish key capabilities needed to rapidly open and operate an airfield under deployed conditions for short periods of time. (Zahn, 2007) In 1999, the transition from AMOG to a new concept called the Contingency Response Group (CRG) was initiated by General John P. Jumper, Commander United States Air Forces in Europe (USAFE). The benefit of the CRG lies in the cross-functionality of its 40 Air Force capabilities under a single commander. (Jumper, 1999) In 2005, the Defense Science Board Task Force on Mobility identified the need for improvements in expeditionary rapid port opening, throughput capabilities, movement synchronization and increased asset visibility. After action reports from contingency operations such as Operations ALLIED FORCE, ENDURING FREEDOM, and IRAQI FREEDOM highlighted the challenges of integrating port and distribution operations. In response to the board, United States Transportation Command (USTRANSCOM) built upon the capability of the CRG and created the Joint Task Force-Port Opening (JTF-PO) concept which reached initial operation capable (IOC) on 2 November 2006. JTF-PO provides the capability to rapidly deploy contingency response Air Force and Army personnel for initial theater Aerial Port of Debarkation (APOD) deployment and distribution operations within 12 hours notice. (USTRANSCOM, 2009) To maintain superiority in this capability, joint force personnel and equipment must maintain an alert status 365 days a year.

Problem Statement

Currently, no capability exists to simulate and measure a Joint Task Force-Port Opening operation in a safe, cost-effective environment in order to determine the best mix of resources needed in order to maximize cargo throughput. The benefits of a good planning tool will allow USTRANSCOM the ability to better estimate resources needed and identify potential bottlenecks through the use of Arena® Simulation software. The logical progression of this research evaluates the factors currently used in the JTF-PO process as well as experimenting with the changes in resource capacities.

Research Objective

The purpose of this research is to create a decision model through discrete-event simulation to support JTF-PO operational planning in order to determine the best mix of resources critical in maximizing cargo throughput under a Humanitarian Assistance/Disaster Response (HA/DR) scenario. Aircraft and cargo data collected from

Operation UNIFIED RESPONSE will be used to input into the model. In order to provide USTRANSCOM a preferred decision model, the following research question (RQ) is addressed:

RQ: What combination of JTF-PO resources maximize the throughput of inbound cargo given the conditions of an HA/DR environment?

In order to answer the research question, the following investigative questions (IQs) are addressed.

IQ1: What is the throughput of inbound cargo under planned concept of operations given the conditions of an HA/DR environment?

IQ2: How does inbound cargo throughput respond to a change in the working maximum on ground (MOG) resources given the conditions of an HA/DR environment?

IQ3: How does inbound cargo throughput respond to a change in the distribution MOG resources given the conditions of an HA/DR environment?

Assumptions/Limitations/Observations

The model created for this research is built upon assumptions derived from Department of Defense Regulations, JTF-PO subject matter experts (SMEs) and the data collected from the Operation UNIFIED RESPONSE after action report (AAR) in Port-au-Prince, Haiti 16 January – 17 February 2010.

Assumptions

1. Operation UNIFIED RESPONSE aircraft arrivals rates and times are representative of future scenarios.

2. 90% of all cargo is palletized at 10,000 pounds each.
3. All palletized cargo is loaded on the standard military 463L pallet.
4. Missing aircraft cargo data is treated as an empty aircraft.
5. No known delays in aircraft ground handling, or cargo distribution were annotated and are assumed out of the model.
6. Service times for aircraft are calculated as the difference between the arrival and departure of all aircraft.
7. Individual actions within the timeframe of aircraft servicing were not captured and therefore assumed to be factored into the service times. They are as follows, aerial port teams' transportation to aircraft, amount of time to download cargo, transport of cargo from aircraft to clearance yard, and any required upload of passengers or cargo.
8. All cargo is destined to the final staging point at the Forward Node.
9. Transport time of taxiing aircraft is held at a constant five minutes.
10. The main supply route is 10 kilometers long.
11. Truck speed on the main supply route is 15 kilometers per hour.
12. Transport time on the main supply route is 40 minutes one way between clearance yard and forward node.
13. Trucks are available at all times to receive cargo at the distribution point.
14. Trucks used by the customers have the same characteristics as the Heavy Expanded Mobility Tactical Truck (HEMTT).
15. Customer trucks take a standard 20 – 30 minutes to load.

Limitations

1. The model only captures the offload and distribution of cargo and does not capture any upload operations.
2. The model remains within the bounds of the JTF-PO operation from aircraft arrival to distribution of cargo.
3. The model considers that cargo is only issued from the distribution yard.
4. The model does not consider passenger processing operations.

Observations

1. High fidelity of aircraft arrival data from AAR:

    Of the 3,006 reported aircraft arrivals in 37 days, 2,561 arrivals in 32 days were recorded (85% of reported missions on the after action report).

2. High fidelity of aircraft service times with n > 12 arrivals into the location:

    Of the 2,561 arrivals into the location, 94 different aircraft types were recorded. Any aircraft that arrived more than 12 times, and were recorded as being serviced, were selected to use in the simulation. This resulted in a sampling of the top 20 aircraft with an overall n = 2,300 arrivals serviced (99% of collected aircraft arrival data).

3. Moderate fidelity of aircraft cargo weight data collected from aircraft service times:

    Of the 2,300 aircraft serviced, 882 aircraft were identified as cargo carrying aircraft; 516 of those aircraft were recorded with cargo weight data (59% of collected cargo aircraft service data).

4. 82% of aircraft arrived via US commercial or international thus a majority of the cargo was not in the traditional 463L pallet configuration. Cargo arrived loose, civilian pallet sized (1.5 times larger than the 463L pallet) or warehouse skid configuration. For reporting, all cargo was converted to a 463L equivalent pallet.

Summary

This research will aim to develop a simulation model that enables USTRANSCOM the ability to evaluate and make informed decisions on the amount of resources needed to deploy a JTF-PO in a Humanitarian Assistance/Disaster Response scenario.

II. Literature Review

Introduction

This chapter will provide background in regards to the purpose of this research. The first section will discuss the requirements of United States Transportation Command's Joint Task Force-Port Opening (JTF-PO) Concept of Operations (CONOPS). This will be followed by a description of Operation UNIFIED RESPONSE and the JTF-PO involvement in support of the humanitarian assistance provided to the city of Port-au-Prince, Haiti following the devastating 7.0 earthquake in early 2010. Finally, the chapter will conclude with a discussion of previous research that utilized simulation as a tool for logistic studies.

Joint Task Force-Port Opening

Humanitarian operations in Central Command (Pakistan earthquake), Pacific Command (Operation UNIFIED ASSISTANCE) and Northern Command (Hurricane Katrina) presented the need for a better distribution capability. (USTRANSCOM, 2009) Furthermore, contingency operations such as Operations ALLIED FORCE, ENDURING FREEDOM and IRAQI FREEDOM re-iterated the need for the same. (USTRANSCOM, 2009) The 2005 Defense Science Board Task Force on Mobility identified the need for improvements on expeditionary rapid port opening and throughput capabilities, movement synchronization and increased asset visibility. (USTRANSCOM, 2009) Air Mobility Command (AMC) already maintains the capability to support USTRANSCOM requirements for Aerial Port of Debarkation (APOD) contingency operations through the use of its Contingency Response Groups (CRG), but lacks the distribution surface capability to support a joint distribution network. (USTRANSCOM, 2009) This established a need to create a rapid response Army distribution unit to supplement the shortfall capability that has been desired on many AARs over the years. The Rapid Port Opening Element (RPOE) was created from a series of Army transportation and supply capabilities and resides under the control of the Surface Deployment and Distribution Command (SDDC). Together, the two units form what is known as a Joint Task Force-Port Opening (JTF-PO).

USTRANSCOM (2009) defines the mission of a JTF-PO in its Concept of Operations (CONOPS) below:

> "Provide a joint expeditionary capability to rapidly establish and initially operate a port of debarkation and distribution node, facilitating port throughput in support of combatant commander executed contingencies.
> The JTF-PO combines Air Force and Army capabilities to provide the CDR USTRANSCOM with a ready-to-deploy, jointly trained force for rapid port opening and establishing the initial distribution network. JTF-PO facilitates Joint Reception Staging Onward Movement and Integration (JRSO&I) (JP 4-01.8, 13 June 2000) and theater distribution (JP 4-01.4, 9 April 2002) by providing an effective interface with the theater Joint Deployment and Distribution Operations Center (JDDOC) and other C2 organizations from the onset of operations. JTF-PO functions are listed below."

1. APOD assessment
2. Distribution network assessment
3. Establishment of C2 with connections to theater JDDOC and functional components
4. APOD opening and initial operation
5. FN opening and management
6. Cargo and passenger transfer operations

7. Movement control including coordination for onward movement of arriving cargo and passengers
8. Establishment of joint ITV and RFID network

In order for the JTF-PO to achieve the desired capabilities required by the supported Combatant Commander (CCDR), a list of shortcomings previously identified from past operations is matched to JTF-PO capability responses in Table 1.

Table 1: JTF-PO Shortcomings & Associated Capabilities (USTRANSCOM, 2009)

APOD Distribution Shortcoming	JTF-PO Capability
Ad Hoc Deployment/Distribution C2	Jointly trained & jointly led Air and Surface elements w/habitual relationships and supporting communications systems
Limited capability to establish FN & network	Designed to assess and open a FN & network associated with APOD
Limited ability to rapidly clear cargo	Organic or contract transportation to rapidly clear cargo to FN
Limited initial port assessment	Joint Assessment Team (JAT) to conduct focused APOD airfield and distribution assessment
Limited movement control	Dedicated Surface element to conduct movement control operations
• Limited capability to coordinate cargo onward movement	Dedicated Surface element to coordinate cargo onward movement
Limited ITV	Organic ITV (including RFID) to provide visibility of forces/cargo at APOD and node

USTRANSCOM (2009) identify the throughput capability of the APOD mission through the CONOPS below:

> "A JTF-PO APOD has a designed capability to handle a working Maximum on Ground (MOG) of two C-17s at a time, operating 24-hour/7-days per week operations in no-/low-light conditions. A JTF-PO can receive, temporarily stage and/or transload onto surface transport to one forward distribution node (within 10 KM of APOD) 560 short tons (combination of rolling stock and cargo) in a 24-hour period. This planning figure assumes that 90 percent of the cargo arrives on single 463L pallets (average pallet weight 4,000 lbs) and remains on 463L pallets for onward movement to the follow-on theater Forward Node (FN) or to destination."

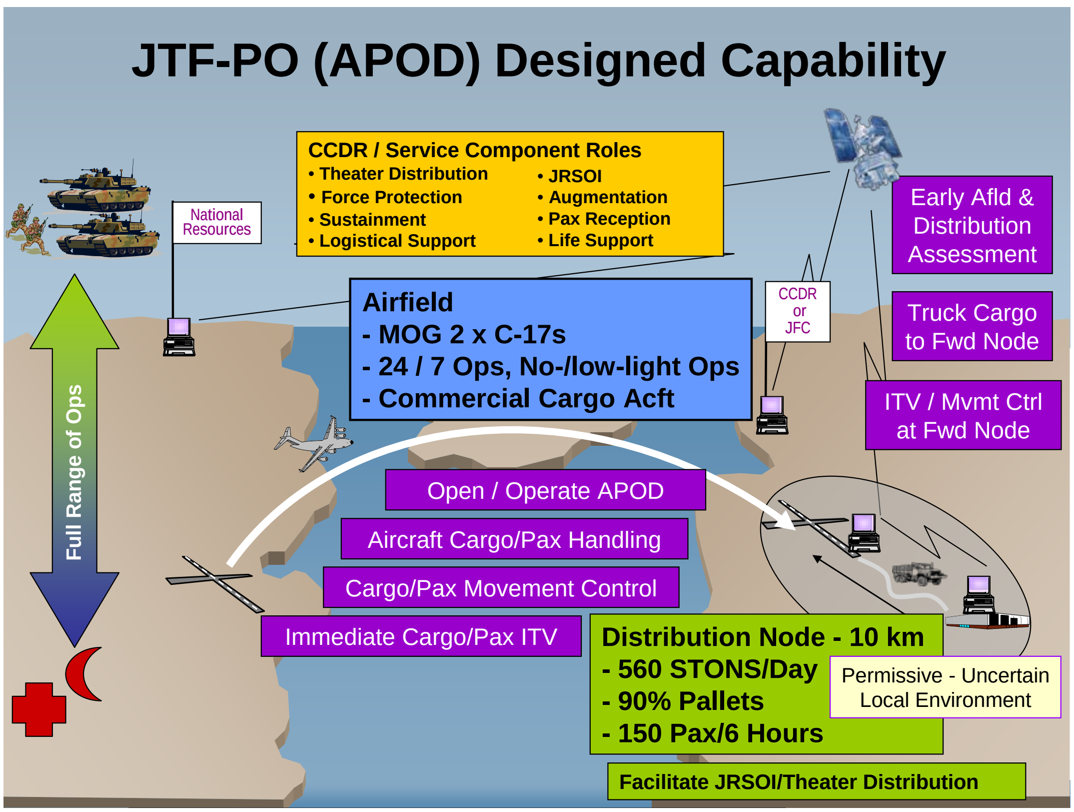


Figure 1: JTF-PO Operational View – Designed Capability (USTRANSCOM, 2009)

The JTF-PO capability is packaged into three Courses of Action (COAs) and is based on likely employment scenarios. The scenarios in Table 2 are designed to offer decision makers the ability to easily tailor JTF-PO forces into deployable configurations under predefined/baseline configurations. (USTRANSCOM, 2009) This research will capture the JTF-PO Heavy Footprint Capability COA due to the nature of the data obtained from historical records.

Table 2: JTF-PO Planning Scenarios (USTRANSCOM, 2009)

JTF-PO Heavy Footprint / Capability • Austere airfield (bare base) • Uncertain Environment, Significant Contingency • 24/7, No-/Low-light ops, MOG 2xC-17s • 90% pallets, 560 Short Tons (STONS)/day, 150 pax/6 hours • Node 10km off APOD, no HN/Commercial trucks	**JTF-PO Heavy Airlift** 9 Surface Element 7 Air Element 16 C17 equivalent (estimated)
JTF-PO Medium Footprint / Capability • Established airfield • Permissive Environment, Major Humanitarian Assistance Disaster Relief (HA/DR) • 24/7, Night ops , MOG 2xC-17s • 90% pallets, 560 STONS/day • Node 10km off APOD, HN/commercial trucks	**JTF-PO Medium Airlift** 5 Surface Element 5 Air Element 10 C17 equivalent (estimated)
JTF-PO Light Footprint / Capability • Established airfield • Permissive Environment, Moderate HA/DR • 12/7, Daylight only ops, MOG 1xC-17 • 90% pallets, 140 STONS/day • Node adjacent to parking ramp	**JTF-PO Light Airlift** 3 Surface Element 3 Air Element 6 C17 equivalent (estimated)

Currently, USTRANSCOM develops and coordinates joint exercises in order to provide training opportunities for JTF-PO personnel and CCDR operational staffs. The training events also provide the opportunity to identify, test and validate procedures and processes for opening distribution networks. (USTRANSCOM, 2009) Though it is necessary to train for experience, it is a costly way to do it solely to identify, test and validate new concepts.

Operation UNIFIED RESPONSE

On 12 January 2010, a 7.0 magnitude earthquake rocked Port-au-Prince, Haiti leaving the city demolished and thousands of people desperate for international aid. Transportation infrastructure was demolished on all accounts to include the main seaport and border crossing routes. The Toussaint L'Ouverture International Airport sustained damage to its facility, but the airfield was still usable. It was clear the only way to get relief into the hands of Haitian people was to move in by air. Initial Air Force capabilities entered 24 hours after the earthquake from the 1st Special Operations Wing (SOW) from Hurlburt Field, Florida. The unit brought with them the capability to control air traffic arrivals into the heavily congested single runway and single taxiway airport. (JTF-PO/CC, 2010)

Figure 2: Toussaint Louverture International Airport (Google Earth)

On 14 January 2010, USTRANSCOM tasked an Air Force CRG and Army RPOE unit for the first time to form the JTF-PO capability. The mission was to establish command and control, aerial port operations, quick-turn aircraft maintenance, and a distribution network in order to maximize humanitarian assistance throughput. (JTF-PO/CC, 2010)

The JTF-PO established operations at the east end of the ramp and consisted of the JTF-PO camp, cargo yard, road, and forward cargo node. The JTF-PO camp was the home of leadership facilities used to conduct command and control of airfield and distribution network operations. The cargo yard was the entrance of cargo into the distribution network and consisted of both Air Force and Army personnel tasked to sort and determine which items move to the forward cargo node. The road, also known as the Main Supply Route (MSR), was used to transport cargo between the cargo yard and forward cargo node. The forward cargo node was the location tasked to distribute the cargo to its owners. (Fisher, 2011)

Figure 3: JTF-PO Operations, Operation UNIFIED RESPONSE (JTF-PO/CC, 2010)

Maximum on Ground (MOG) is used to describe the maximum number of aircraft on the ground and is broken down into parking MOG and working MOG. Parking MOG refers to the maximum number of aircraft that can be parked at one time on an airfield. Working MOG identifies the maximum number of aircraft that can be worked (parked and serviced) at one time. (JTF-PO/CC, 2010) The more restrictive of the two measures generally equates to the limiting factor of MOG. (AFI10-403, Deployment Planning and Execution, 13 January 2008)

The parking ramp in Haiti consisted of ten C-17 equivalent parking spaces and was managed by aircraft maintenance. The thirteen-man maintenance package planned to work a parking MOG capability of two but was expected to work four at one time. The best way to meet the expectations was to split each shift of maintainers in half, allowing one team to work half the ramp and the other team to work the other half.

(Wallwork, Gunn, Morgan, & Wilcoxson, 2010) Furthermore, the aerial port teams utilized the same tactics and split shifts in order to download aircraft more efficiently. The decision for both capabilities allowed faster turn-around time of aircraft through the airfield. (Fisher, 2011)

Figure 4: Parking Ramp, Operation UNIFIED RESPONSE (JTF-PO/CC, 2010)

Though the parking MOG in Haiti was ten, the initial working MOG capability for aerial port teams was two. A description of Figure 5 is taken from the AAR from the JTF-PO/CC (2010) and stated below:

> "The Figure visually depicts the gaps between our working MOG capability and the required working MOG based on the mission flow. The Figure shows we were able to meet the demand during the 2nd week, and exceed the demand in weeks 3 – 5. The excess capability we had served as insurance to absorb a spike in demand."

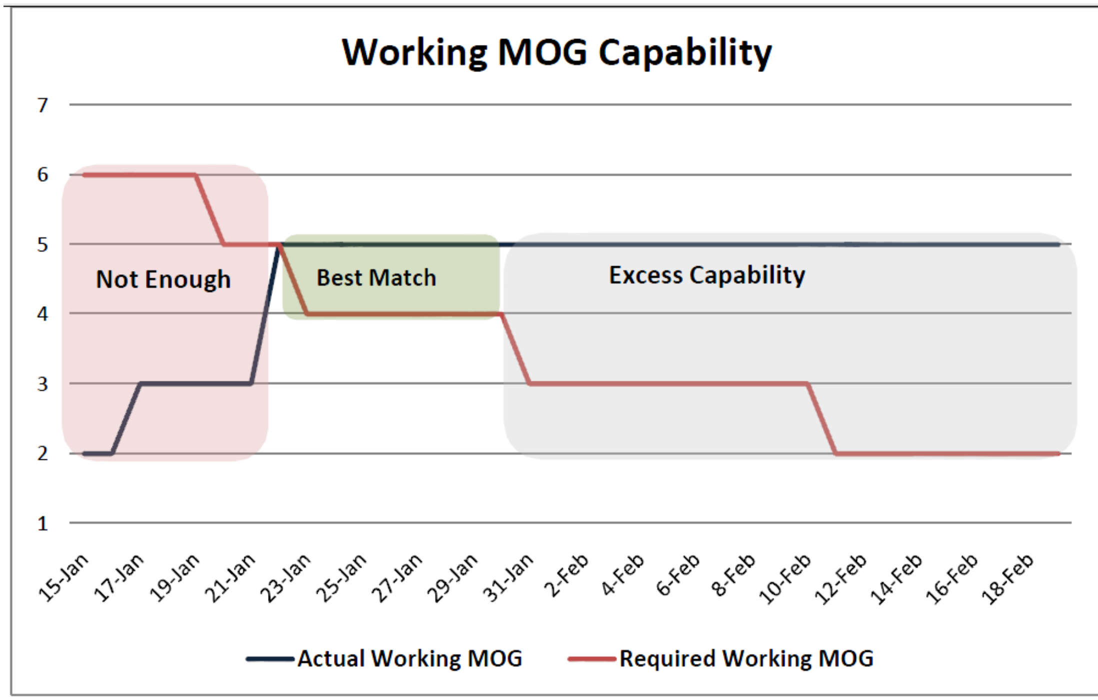


Figure 5: Working MOG Capability (JTF-PO/CC, 2010)

Furthermore, the AAR stated there were challenges associated with calculating the required working MOG and are explained below:

> "The other challenges in reporting and analyzing working MOG for this operation were the wide variety of customers and help the JTF-PO received from other organizations. The JTF-PO received MHE, manpower and equipment assistance from the United Nations (UN), Joint Special Operations Air Component (JSOAC), Canadians and the Government of Haiti (GoH). In addition, some aircraft required no downloading assistance (negative cargo) or were self downloading. All of these factors were fully incorporated into the advertised working MOG capability."

Though maximizing humanitarian assistance throughput was the mission of the JTF-PO, so was returning operations back to the GoH. Prior to the departure of the JTF-PO, the GoH resumed commercial operations on 19 February with the first American Airlines flight arriving on 19 February 2010. (Air Forces Southern, Public Affairs, 2010) In 37 days, the JTF-PO was able to amass working 3,006 relief missions, download over 30.9 million pounds of cargo and evacuate 15,495 American Citizens (AMCITs). (JTF-PO/CC, 2010)

Table 3: Mission Data for Operation UNIFIED RESPONSE
14 Jan – 19 Feb 2010 (JTF-PO/CC, 2010)

MISSION DATA Operation UNIFIED RESPONSE	
C-17 Missions/Sorties	253/506
C-130 Missions/Sorties	283/566
US Commercial Missions/Sorties	1339/2678
International Missions/Sorties	1131/2262
TOTAL Missions/Sorties	3006/6012
Air Evacuation Missions:	301 Litter, 10 Ambulatory
Off-Load Passengers:	9,509
Off-Load Cargo:	15,450 ST
On-Load Passengers:	15,495
On-Load Cargo:	253 ST

Logistics Studies Involving Simulation

Over the last 20 years, the U.S. military has become more reliant on the force projection posture rather than strategic prepositioning. McKinzie and Barnes (2004) identified the need for simulation analysis due to the ever-shrinking military budget and force size which emphasized the need to efficiently deploy personnel, equipment and support equipment. The study discusses the overview of the different types of strategic mobility models used in the defense transportation system and their advantages and disadvantages. Strategic mobility models are logistics models which represent the flow of cargo and passengers from the U.S. to overseas theaters. (McKinzie & Barnes, 2004) Of the different types of models discussed, the Joint Flow and Analysis System for Transportation (JFAST) and Mobility Simulator (MOBSIM) are the closest simulation models related to this research. JFAST is a multimodal transportation analysis model designed to forecast transportation requirements and evaluate what-if scenarios.

(McKinzie & Barnes, 2004) MOBSIM is a discrete-event stochastic simulation tool that deals with multiple modes of transportation. (McKinzie & Barnes, 2004)

JFAST and MOBSIM use Time Phased Force Deployment Data (TPFDD) as input into their modeling and are easily entered manually if needed which leads to a deterministic approach to modeling. Creating the TPFDD is appropriate to use when sufficient planning is available and well-trained logistical and operational planners are available. However, in a dynamic response situation, (as-is the JTF-PO operation), it may be too time consuming in order to make appropriate decisions on-time. (Yildirim, Tansel, & Sabuncuoglu, 2009) Furthermore, Yildirim and others (2009) identify the need for a fast and accurate tool that takes into account the stochastic nature of events to analyze a military deployment plan.

Though JFAST and MOBSIM have many benefits in modeling multimodal concepts, they have disadvantages too. They lack the finer details that organizations may wish to input into the models. Though it would be preferred to include the details into JFAST and MOBSIM, it would ultimately cause the models to grow to unmanageable sizes requiring impractical execution times. (McKinzie & Barnes, 2004) Though there is modeling software available to use, this research includes the much needed details of the dynamic JTF-PO operation in order to capture the most likely throughput and resource utilization based on historical data, instead of pre-planned TPFDD data.

As Ciarallo and Hill (2005) identify that defense logistic networks are dynamic in nature, so is the JTF-PO operation. With surge arrivals of aircraft and cargo into defense logistic networks, simulating an entire operation under a single stochastic distribution results in a less than optimal output. An arrival flight traffic model was presented by

Kim, Akinbodunse, and Nwakamma (2005) to simulate time-varying arrivals via airport arrival fixes to a runway. Arena Input Analyzer® was used to generate mathematical expressions, based on the inter-arrival time distribution of aircraft extracted from a Federal Aviation Administration (FAA) database. The simulation was developed to model the holding patterns of aircraft based on varying arrival rates depending on peak arrival periods. Aircraft are then allowed to land under a first-in-first-out (FIFO) manner. The results gave an estimate of the number of flights arriving within a select peak period. (Kim, Akinbodunse, & Nwakamma, 2005)

The task of matching arriving aircraft to parking spaces is related to the berth planning system of container ship operations studied by Legato and Mazza (2001). They developed a discrete event simulation model for the queuing network of the logistics activities related to the arrival, berthing, and departure processes of vessels at a container terminal. The study allowed simulation results to illustrate the use of the model for "what-if" scenarios in the berth planning problem. (Legato & Mazza, 2001)

According to a study compiled by Graves and Higgins (2002), simulation provides a valuable tool for modeling attributes of future systems, and comparing alternate concepts for how systems should be employed. Their application used simulation to determine container- and material-handling equipment requirements for an Army Cargo Transfer Company operating a container terminal at a seaport. The primary measure of interest for the model was the total container throughput and material handling equipment (MHE) utilization. (Graves & Higgins, 2002)

Conclusion

This chapter provided background in regards to the purpose of this research. The first section discussed the requirements of United States Transportation Command's Joint Task Force-Port Opening (JTF-PO) Concept of Operations (CONOPS). This was followed by a description of Operation UNIFIED RESPONSE and the JTF-PO involvement in support of the humanitarian assistance provided to the city of Port-au-Prince, Haiti following the devastating 7.0 earthquake in early 2010. Finally, the chapter concluded with a discussion of previous research that utilized simulation as a tool for logistic studies.

III. Methodology

Introduction

This chapter explains the methodology used to develop the simulation model for evaluating the Joint Task Force-Port Opening operation in HA/DR environments. The first section will define simulation and identify when it should not be attempted to model systems. The next section will identify the overarching requirements of building models in a defense logistics network. This will be followed by a brief introduction to the method of discrete-event simulation. Next, a definition of simulation terms will be introduced in order to provide a framework of understanding discrete-event simulation with Arena® software. Finally, the twelve-step process of simulation model building will be introduced and accompanied by a detailed description of the use of each step in the author's research effort.

Simulation

Simulation is the process of designing and creating a computerized model of a real or proposed system for the purpose of conducting numerical experiments to give a better understanding of the behavior of that system for a given set of conditions. (Kelton, Sadowski, & Sturrock, 2007) The type of modeling approach used for this research is a logical-computer simulation. The logical-computer simulation has the ability to address questions about the model's behavior under faster, safer, and cost-efficient conditions by simply manipulating the program's inputs and logic. (Kelton, Sadowski, & Sturrock, 2007) Furthermore, Kelton and others (2007) explain that computer simulation allows the researcher to duplicate and study complex systems that may not have exact mathematical solutions worked out. Complex systems frequently simulated are airport flight arrivals and distribution networks.

In order to validate the proposed methodology of simulation modeling, it is important to identify when simulation is not appropriate. Banks and Gibson (1997), allows researchers to evaluate when simulation is not appropriate by following ten rules.

1. The first rule identifies that common sense problems should not be simulated.
2. The second rule identifies that problems should not be simulated if they can be solved analytically.
3. The third rule states that simulation should not be used if there is a less expensive method to solve the problem.
4. The fourth rule identifies that a simulation should be avoided if the cost to simulate outweighs the savings benefited from it.
5. The fifth rule states that a simulation should not be performed if there is no availability of time to complete it.
6. The sixth rule states that a simulation should not be performed if there is no availability of resources to complete it.
7. The seventh rule states that simulation is not advised if there is no data available to input into the model.
8. The eighth rule identifies the ability to verify and validate the model; if there are no personnel or time available, simulation is not advised.
9. The ninth rule states that if managers have unreasonable expectations of the results, then simulation should not be completed.

10. Finally, the tenth rule states that simulation should not be considered if the system behavior is too complex to duplicate.

Refuting the ten rules identified in the article support the decision to utilize simulation for the purposes of this research.

Decision Model Requirements

According to Ciarallo and Hill (2005), in order to achieve a defense logistics network that successfully operates in just-in-time/dynamic scenarios, there must be an effective combination of three components – data, decision models, and decision support environments.

Analysis of data on past performance is critical to determine the future consequences of critical decisions made at the present. Incorporating this data into a decision model generates options for resource utilization and identifies potential constraints in the system. (Ciarallo & Hill, 2005) When little data is available for the system, statistical forecasting methods and planning data can be used to fill in the holes.

Decision models based on simulation and optimization, or other frameworks, generates options that examine criteria in one or more performance dimensions. In order for the model to generate reasonable options for the decision maker, the model must represent the expected performance, as well as the possible risk of potential actions. (Ciarallo & Hill, 2005) Through validation methods, expected throughput and resource utilization performances are measured against modeling outcomes values.

Furthermore, decision support environments should allow further evaluation of the solutions suggested by one or more restricted models by considering performance in a number of dimensions. (Ciarallo & Hill, 2005) The models must be flexible enough to include "what-if" scenarios which will allow average users to manipulate parameters based on the needs of the support environment. (Ciarallo & Hill, 2005) Finally, Ciarallo and Hill (2005) identify that simulation is a critical component of the evaluation of decisions in very realistic conditions because of its flexibility and ability to model uncertainty. The model is no use if it is too complicated and does not allow flexibility in developing scenarios for potential future decision making. The result of this study will provide a tool necessary to support all three components of a successful decision model in a defense logistics network.

Discrete-Event Simulation

Discrete-event simulation is the modeling of systems in which the state variable changes only at a discrete set of points in time. (Banks, Carson II, Nelson, & Nicol, 2010) Due to the nature of this research, the approach of discrete-event simulation is employed through the aid of computers in order to "run" rather than "solve" numerical models. The choice of software for modeling is the Rockwell Corporation's Arena® simulation software due to the ability to capture the dynamic nature of the JTF-PO mission. The software generates an artificial history of the system built from model assumptions and observations of each "run" result is collected to be analyzed and to estimate system performance measures. (Banks, Carson II, Nelson, & Nicol, 2010) Though simulation can solve simple mathematical problems, the best use of its capability is performed on complex systems. The JTF-PO and related distribution systems is a perfect match for utilizing simulation because of the complex nature of entity arrivals, service times, and network flow.

Definition of Simulation Terms

There are various parts of a simulation model which are identified by specific terms. This section will define the terms according to the text Simulation with Arena Fourth Edition from Kelton and others (2007) and displays a relationship of the terms in respect to this research.

Entities

Simulation involves "players" called entities that are created automatically to enter a system, seize resources, potentially change state, and then depart the system through a disposal function. There are four categories of entities involved in this simulation, Aircraft, Pallets, Demand and Resource. The Resource entity is used only once to populate the values of each individual resource before the simulation begins. The Aircraft entity is compiled of 20 different types of aircraft that arrive into a system. The Pallet entity is a transformed value derived from a duplicated Aircraft entity which enters a distribution network sub-system process. The Demand entity is used to identify a demand for Pallet entities to depart every six hours. All entities depart their respective systems at the end of their processes.

Attributes

In order to individualize entities, attributes are attached to them. Attributes have common characteristics for all entity types but with different values for each entity. In this simulation, it is most important to individualize the 20 different Aircraft entities. For each Aircraft entity 11 attributes are assigned to them.

Resources

When entities enter a system, they compete for the seizure of resources to service them. When the resources are finished with the entity, they are released and become available to the next entity in the system. In this simulation, 14 resources are created to represent 14 different services needed for each entity (if all required).

Queues

When an entity encounters a resource that is busy, a queue is created. This provides the entity a place to wait until the resource becomes idle. Some queues have capacities that limit the number of entities allowed to wait. In this simulation 20 queues were created under first-in first-out conditions to support the 14 resources in the model.

Variables

A variable is a piece of information that reflects a system characteristic, regardless of the number of entities in the model. They can be accessed by all entities and many can be changed by them. In this simulation, variables serve the purpose of compiling all hard-coded values which are then used to populate every attribute and resource. This equates to 188 different values in the simulation.

Statistical Accumulators

Statistics are collected to report in output performance measure reports. In this simulation, the measures of importance are the number of entities (Pallets) that have passed through the system. Furthermore, the utilization rates for each of the resources are collected.

Events

An event is something that happens at an instant of simulated time that changes attributes, variables, or statistical accumulators. This comes in the form of a creation of some type of entity, its disposal, and the end of a simulation. In this simulation, there are nine particular events created that represent each creation/disposal of the four different entities for the simulated run-time of 30 days.

Model Development

Banks and others (2010) identify a 12-step process in Figure 6 for developing a simulation model which applies to any model building effort; it provides the structure for this research. In Stieglemeiere's research (2006), he breaks-down the description of the process into two halves. The first half, (Steps 1-7), represent the effort undertaken to build, validate, and verify the model. The second half, (Steps 8-12), represent the actual use of a model to analyze a system and make decisions about it. The 12-step process used in this research is described in the following section.

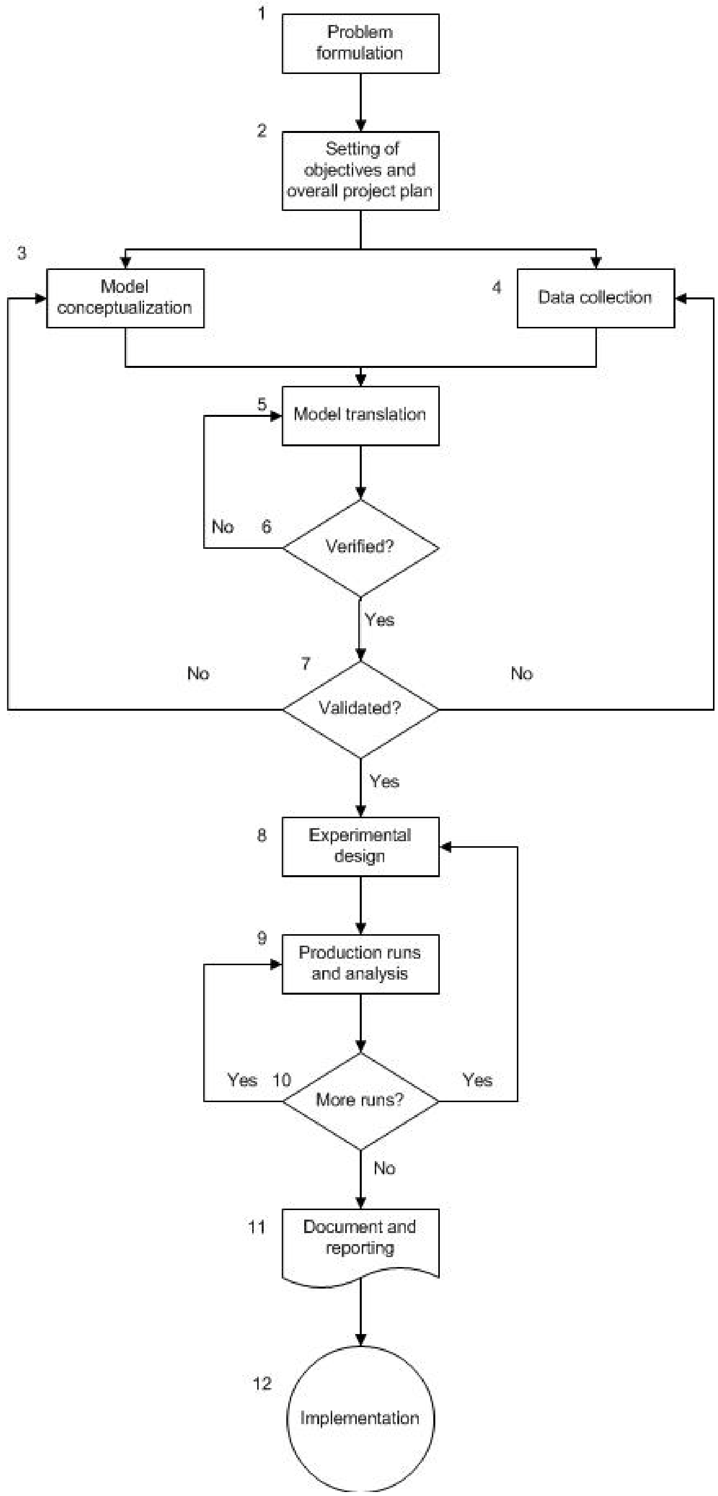


Figure 6: Steps in a Simulation Study (Banks, Carson II, Nelson, & Nicol, 2010)

The 12-Step Modeling Process

Step 1: Problem Formulation

The first step to solving any problem in a study is to formulate a statement of the problem. (Banks, Carson II, Nelson, & Nicol, 2010) USTRANSCOM clearly defined the problem that there is currently no capability to model a JTF-PO operation in a safe, cost-effective environment in order to predict throughput of cargo based on the availability of resources.

Step 2: Setting of Objectives and Overall Plan

The objectives indicate the questions to be answered by simulation. (Banks, Carson II, Nelson, & Nicol, 2010) The purpose of this research is to create a decision model through discrete-event simulation to support JTF-PO operational planning in order to predict throughput of cargo under a HA/DR scenario.

Step 3: Model Conceptualization

This step is by far the lengthiest step in the modeling process in that model construction is more an art than a science. The art of modeling is enhanced by an ability to abstract the essential features of a problem, to select and modify basic assumptions that characterize the system, and then to enrich and elaborate the model until a useful approximation results. (Banks, Carson II, Nelson, & Nicol, 2010) Simulation modeling is an iterative process that requires a modeler to start with a simple model and develops it to mirror the real-world workings of the system. The model for this research was logically built from the experience of subject matter experts, and was constrained by the available data. Furthermore, involvement of subject matter experts contributed to enhance the quality of the resulting model and increase the confidence of its application. Figure 7 identifies the conceptual model in its simplest form.

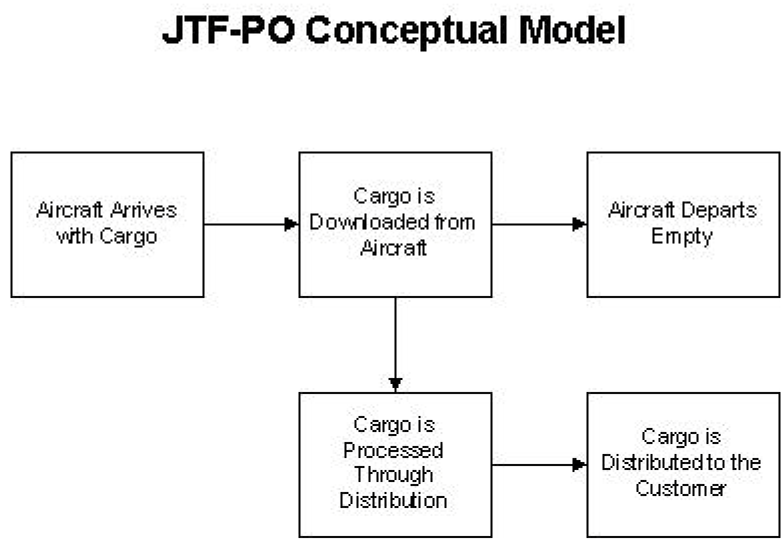


Figure 7: JTF-PO Conceptual Model

Step 4: Data Collection

Historical data collection is performed during this step and is utilized in conjunction with the conceptual model building. Normally, the objectives of this study dictate the kind of data to be collected. This research utilized a reverse approach. Data was collected prior to model conceptualization. This provided limitations in the model building. The data was collected from two separate subject matter expert (SME) sources Command and Control leadership and Air Terminal Operations Center personnel from Operation UNIFIED RESPONSE and are categorized below with varying levels of fidelity.

1. High fidelity of aircraft arrival data from AAR:

Of the 3,006 reported aircraft arrivals in 37 days, 2,561 arrivals in 32 days were recorded (85% of reported missions on the after action report).

2. High fidelity of aircraft service times with n > 12 arrivals into the location:

   Of the 2,561 arrivals into the location, 94 different aircraft types were recorded. Any aircraft that arrived more than 12 times, and were recorded as being serviced, were selected to use in the simulation. This resulted in a sampling of the top 20 aircraft with an overall n = 2,300 arrivals serviced (99% of collected aircraft arrival data).

3. Moderate fidelity of aircraft cargo weight data collected from aircraft serviced

   Of the 2,300 aircraft serviced, 882 aircraft were identified as cargo carrying aircraft; 516 of those aircraft were recorded with cargo weight data (59% of collected cargo aircraft service data).

Table 4: Fidelity Levels for Aircraft and Cargo Data

Type Data	**Collected Data**	**Final Data Used**	**Level of Data Fidelity**
Aircraft Arrival Times	3,006 Reported Arrivals	2,561 Arrived	85%
Aircraft Service Times	2,331 Type AC Arrivals with n > 12	2,300 Serviced	99%
Aircraft Cargo	882 Cargo Aircraft Capable	516 Cargo	59%

Table 5: Type Aircraft Serviced Statistics

	AC Type	# AC Arrived	% AC Arrived	# AC Serviced	% AC Serviced	# AC with Cargo Weight	% AC with Cargo Weight
1	TURBOPROP	769	32.99%	754	32.78%	NA	NA
2	C130	392	16.82%	388	16.87%	155	39.95%
3	C17	268	11.50%	268	11.65%	243	90.67%
4	LEARJET	209	8.97%	205	8.91%	NA	NA
5	C2	162	6.95%	160	6.96%	NA	NA
6	B727	83	3.56%	83	3.61%	32	38.55%
7	GULFSTREAM	83	3.56%	81	3.52%	NA	NA
8	B737	77	3.30%	77	3.35%	NA	NA
9	CN235	46	1.97%	46	2.00%	NA	NA
10	IL76	45	1.93%	45	1.96%	17	37.78%
11	B757	31	1.33%	31	1.35%	22	70.97%
12	C12	29	1.24%	29	1.26%	NA	NA
13	DASH8	24	1.03%	24	1.04%		NA
14	L100	22	0.94%	22	0.96%	21	95.45%
15	B767	21	0.90%	20	0.87%	9	45.00%
16	JETSTREAM	17	0.73%	16	0.70%	NA	NA
17	B707	14	0.60%	14	0.61%	NA	NA
18	B747	13	0.56%	13	0.57%	12	92.31%
19	A310	14	0.60%	12	0.52%	NA	NA
20	AN12	12	0.51%	12	0.52%	5	41.67%
	Totals	**2331**		**2300**		**516**	**58.5%**

Cleaning the data requires domain SME knowledge which was obtained from the source of the data collectors in the operation. In order to hold the assumption of zero delays in aircraft ground handling, pair-wise deletion was conducted on aircraft with service times that exceeded 360 minutes (or six hours). The rationale for deleting the C-130 and C-17 aircraft is due to maintenance issues which held the aircraft on the ground for longer than planned. (Jones, 2011) The rationale for deleting the remaining aircraft is due to their double-blocking to another parking apron prior to their final departure. (Jones, 2011) Since aircraft service times were calculated as time between arrival and departure, these aircraft were removed from the model.

Table 6: AC > 360 Minutes Service Time (6 Hours)

AC Type	Deleted
C130	4 Deleted
C17	3 Deleted
PROP	30 Deleted
LEARJET	3 Deleted
C2	2 Deleted
B727	1 Deleted
GULFSTREAM	2 Deleted
B737	2 Deleted
CN235	1 Deleted
IL76	6 Deleted
B757	1 Deleted

In order to show validation in the data collected from the CRG, daily aggregated aircraft arrivals were obtained from the Federal Aviation Administration's Enhanced Traffic Management System Counts (FAA ETMSC) and were compared with the CRG totals. Both of the collected totals follow the same negative trend, as can be seen by Figure 8, with a residual difference mean of 28 arrivals and standard deviation of 12 arrivals. The reason for the difference in arrivals is due to the CRGs ability to collect unscheduled aircraft arrivals from day one. Though the FAA set up a slot-management system to schedule all arrivals a few days after the earthquake, unscheduled aircraft were still arriving to the location. Therefore on-scene data collection represents the most accurate arrival data. (Jones, 2011)

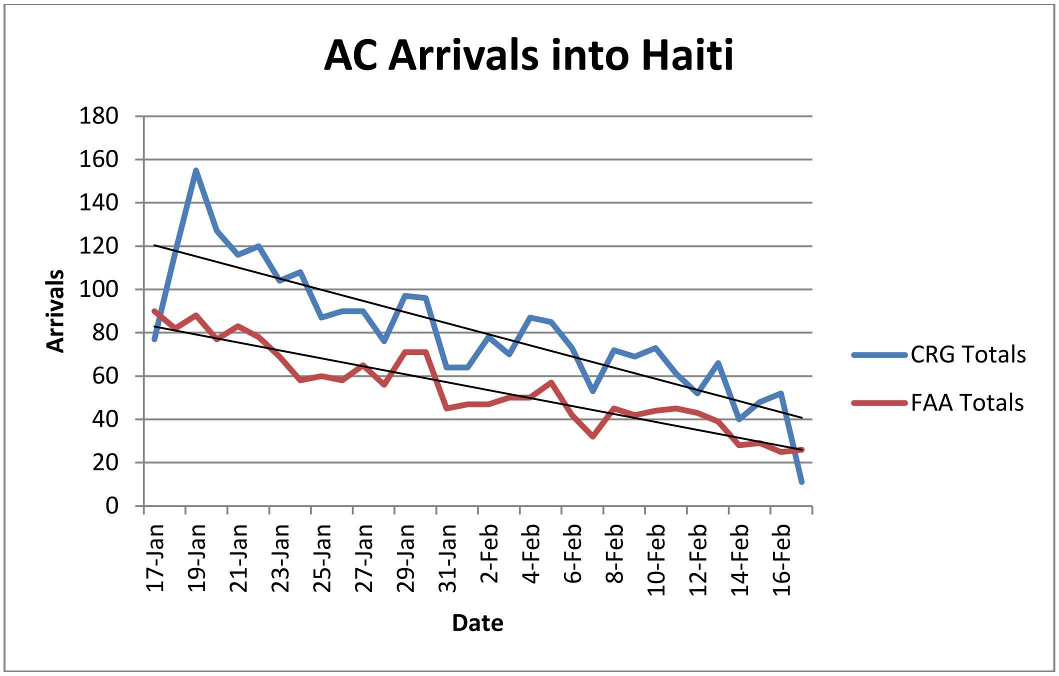


Figure 8: Daily Aircraft Arrivals into Haiti

There were two significant challenges the RPOE faced for reporting the amount of cargo distributed. These were due to the fact that 82% of aircraft arrived via US commercial or international carriers. First, the majority of aircraft arrivals were not tracked with radio frequency identification (RFID) tags. This challenge forced the RPOE to manually track cargo from arrival into the airport through departure to the customer. (Fisher, 2011) Second, the cargo, loaded onto the majority of arrivals, was not in the traditional US military 463L pallet configuration. Instead, cargo arrived primarily in warehouse skid configuration. For reporting this type of cargo, a simple mathematical conversion was used to transform four skids into one 463L pallet equivalent. (JTF-PO/CC, 2010)

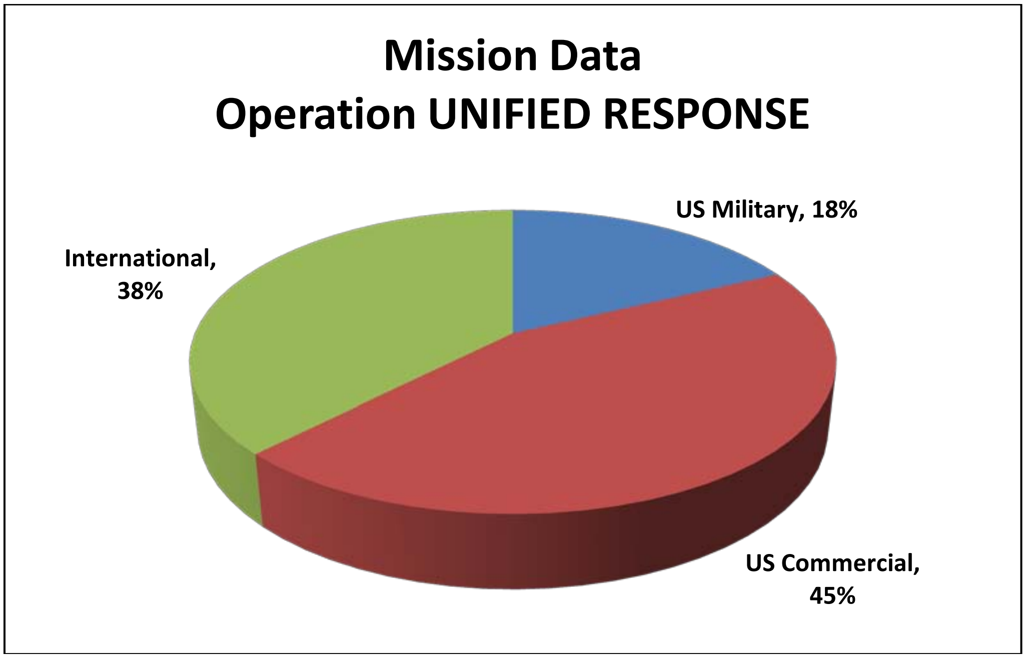


Figure 9: Airlift Carriers

Figure 10 displays the analysis of cargo that is stored in the forward node at the end of each 2400 hour day. It can be seen that cargo positively trends upward until it reaches 89% of its capacity (450 pallets) on 2 February and remains constant until 11 February when it steadily trends negatively downward. This identifies a peak capacity period within that timeframe.

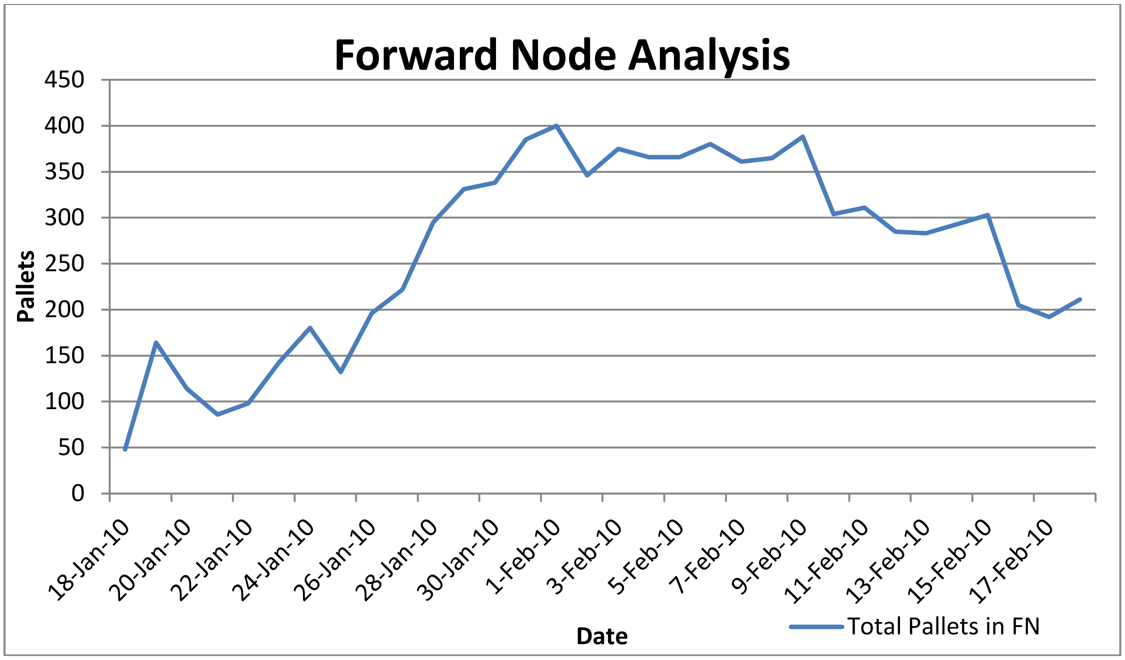


Figure 10: Forward Node Analysis (Kuppinger, 2011)

In Figure 11, the gradual die-down in cargo sent to the forward node correlates with the gradual die-down of aircraft arrivals from Figure 8. Using face validity, both aircraft arrival and cargo distribution data sets should result in a reasonable simulation model for evaluating cargo throughput in humanitarian operations because they exhibit the same negative trend.

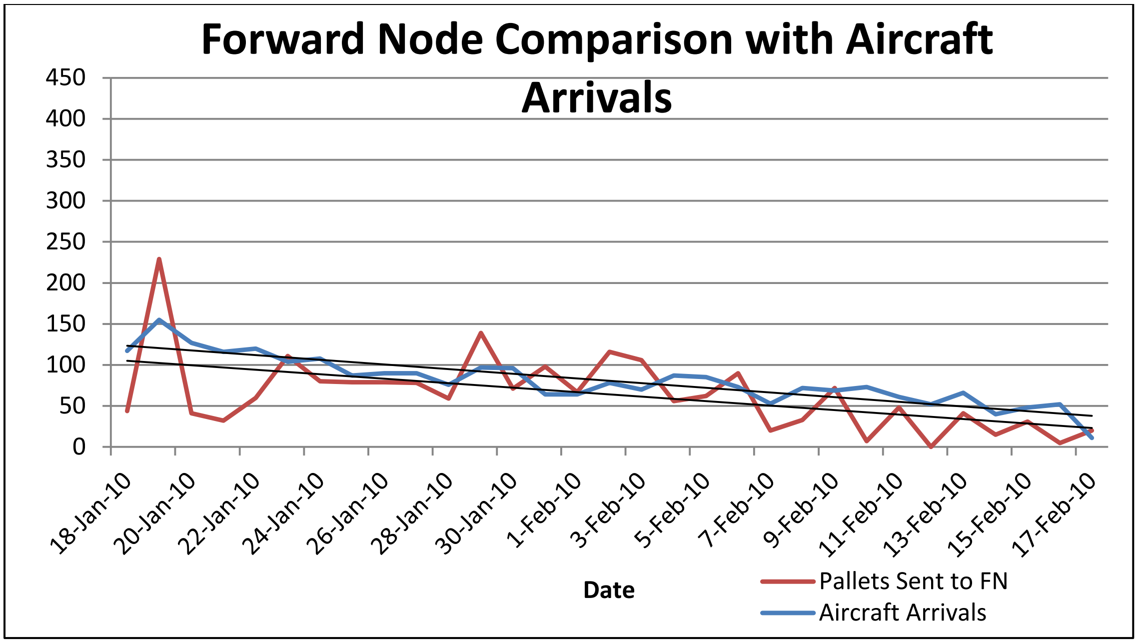


Figure 11: Forward Node Comparison with Aircraft Arrivals

Step 5: Model Translation

This step translates the conceptual model into either simulation language or special-purpose simulation software. For the purpose of this research, Arena® simulation software was utilized. Utilizing this software greatly reduces the time to develop the model and is flexible enough to handle dynamic defense logistic networks. Figure 12 defines the various modules used in the simulation software. The final simulation consists of two parts, an outer model and cargo distribution submodel which can be seen in Figure 13 and Figure 14. A more detailed view of each of the models subparts are shown in Figure 15 through Figure 22.

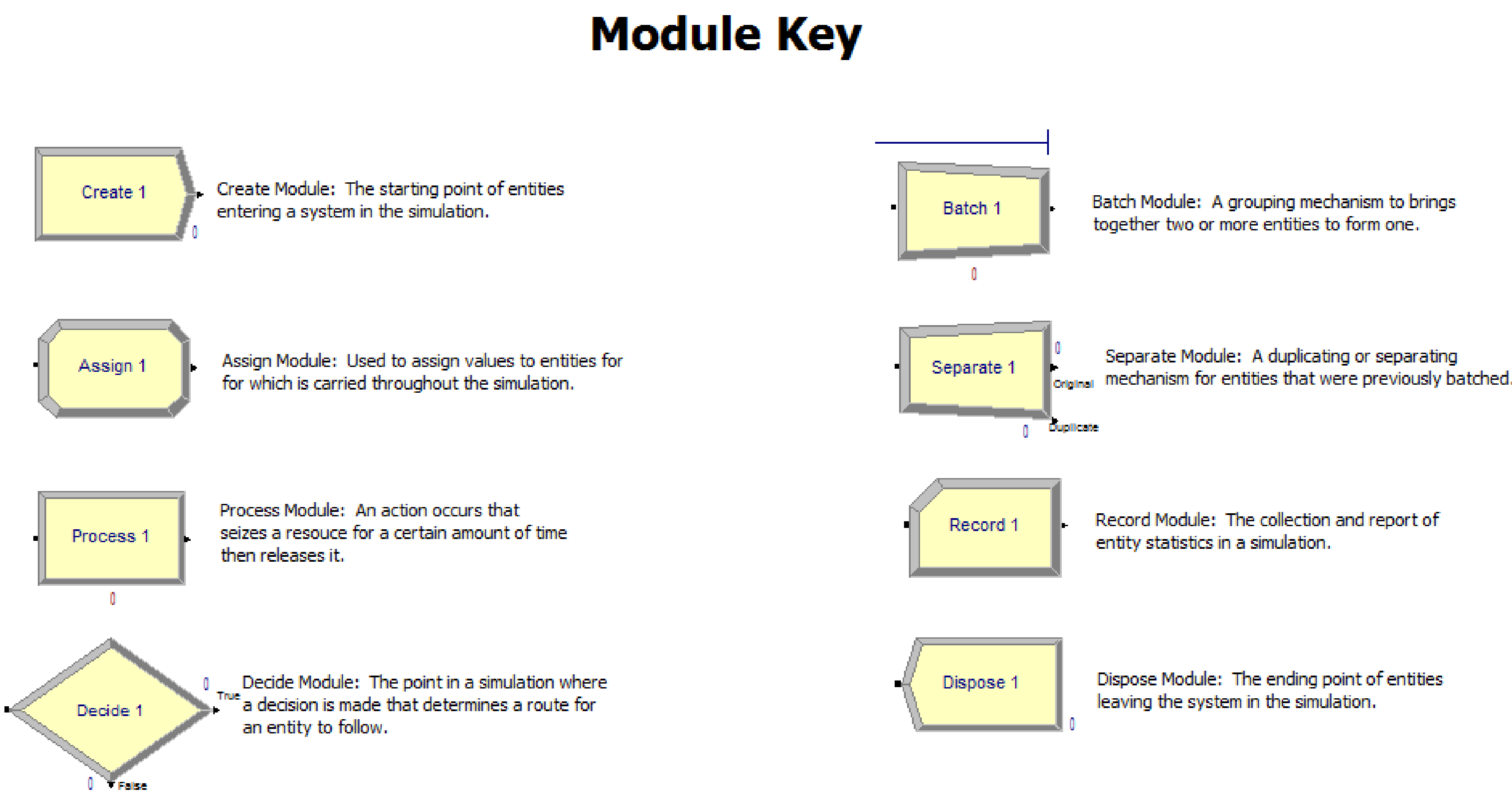


Figure 12: Module Key

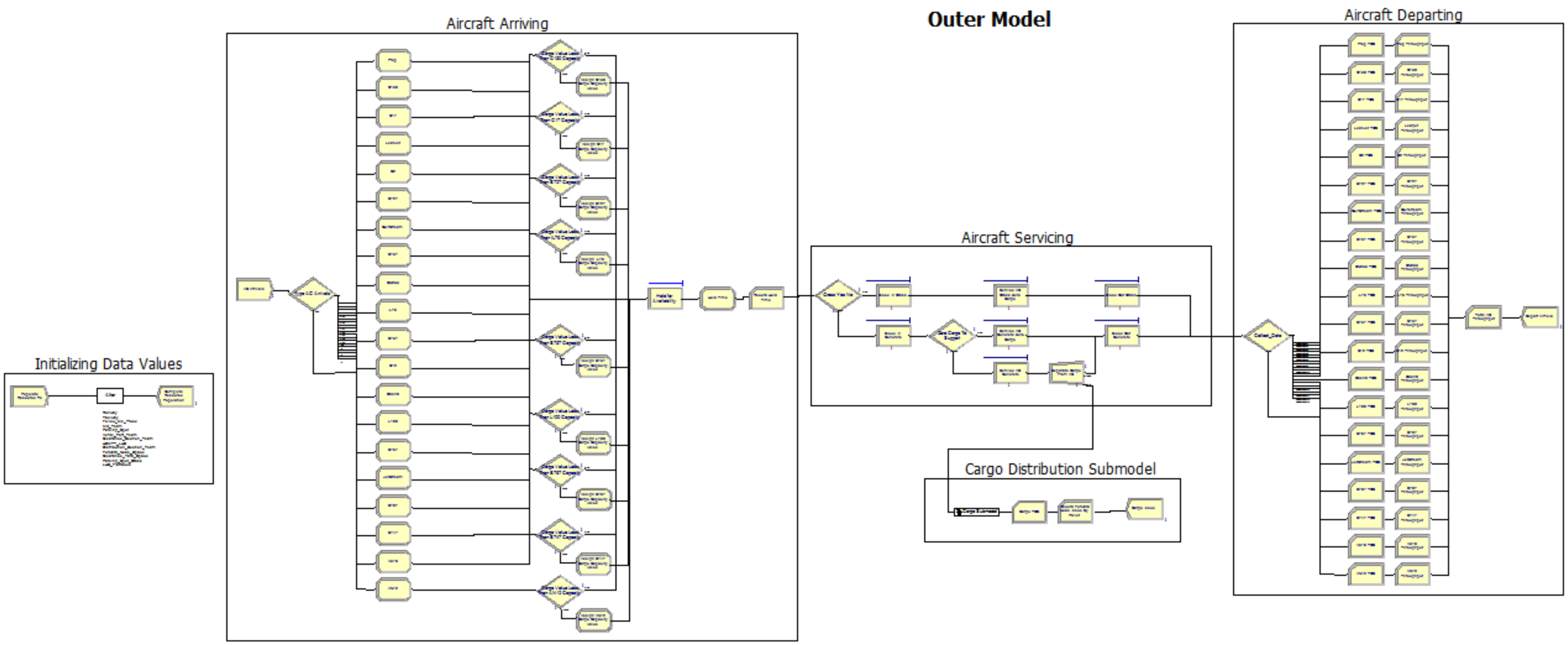


Figure 13: Outer Model

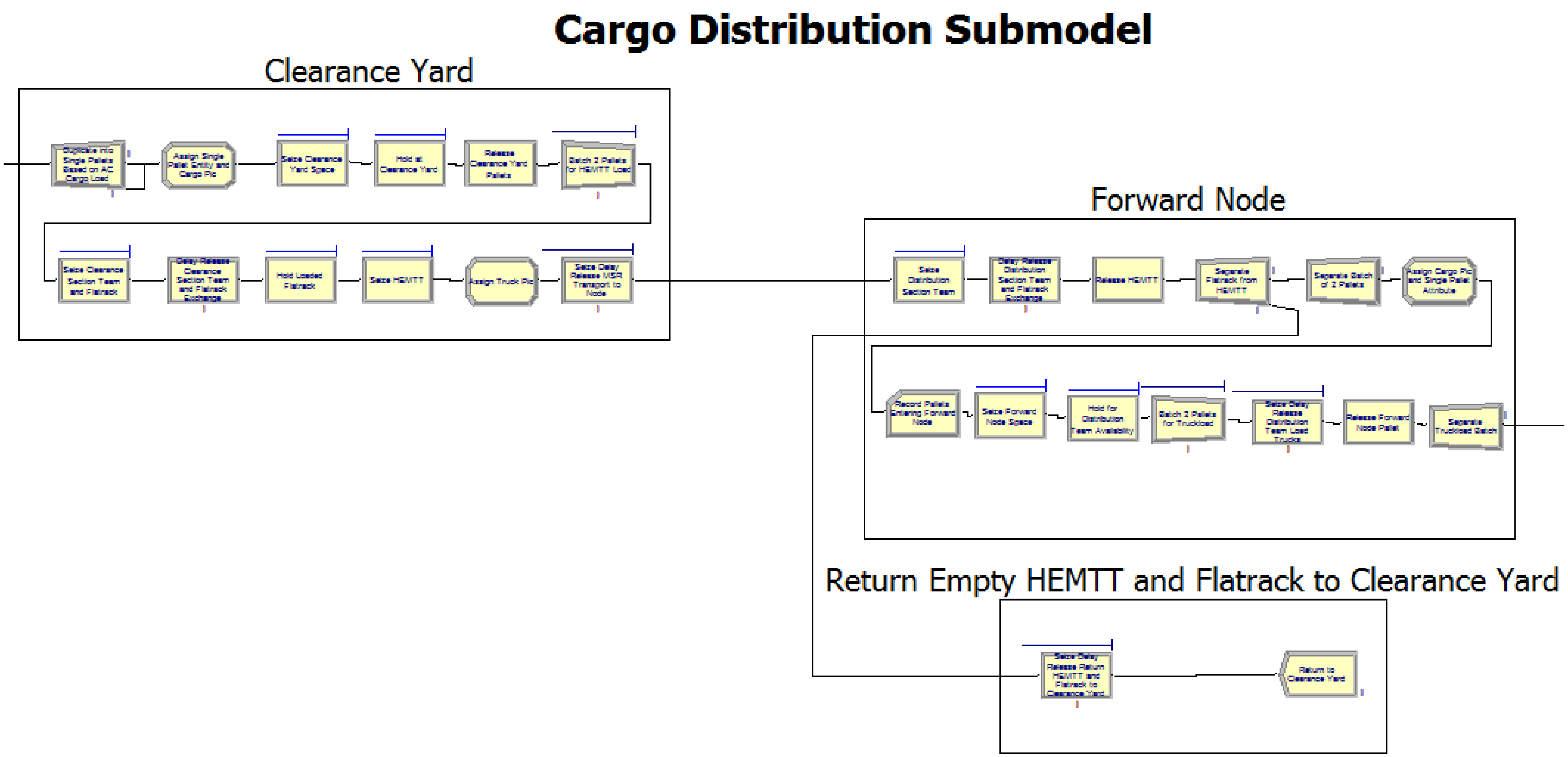


Figure 14: Cargo Distribution Submodel

Figure 15 identifies the initialization of discrete variables to populate the number of resources needed to execute the simulation. This step is accomplished automatically prior to execution of the full simulation. Table 7 identifies the number of resources used in the simulation based on the data collected from Operation UNIFIED RESPONSE. The Runway and Taxiway are utilized to land and taxi aircraft to their parking spots. The Follow_Me_Truck is a vehicle that greets aircraft at a taxiway then leads it to a parking spot. The MX_Team (Maintenance_Team) are individuals used to marshal aircraft into parking. The Parking_Spot is C-17 equivalent sized parking spots on the parking apron. The Parking_Spot_Grass is C-17 equivalent sized parking spots off the parking apron. The Aerial_Port_Team are teams of individuals used to download the cargo from aircraft and deliver to the clearance yard. The Clearance_Yard_Space is the cargo yard nearest to the flight line with capability of holding 463L equivalent sized pallets. The Clearance_Section_Team are teams of individuals used to transfer cargo from the clearance yard to a Heavy Expanded Mobility Tactical Truck Load Handling System (HEMTT_LHS) destined to the forward node. The HEMTT_LHS are trucks utilized to transfer cargo from the clearance yard to the forward node via a Main Supply Route (MSR). The LHS_Flatracks are platforms used to transition two 463L equivalent sized pallets of cargo each from the ground onto the back of the HEMTT for transport. The MSR is the path the HEMTTs travel between the clearance yard and forward node (infinite quantity indicates that a limitless number of HEMTTs can utilize the MSR at one time). The Forward_Node_Space is the cargo yard at the distribution point with capability of holding 463L equivalent sized pallets. The Distribution_Section_Team are teams of individuals used to distribute cargo to a customer.

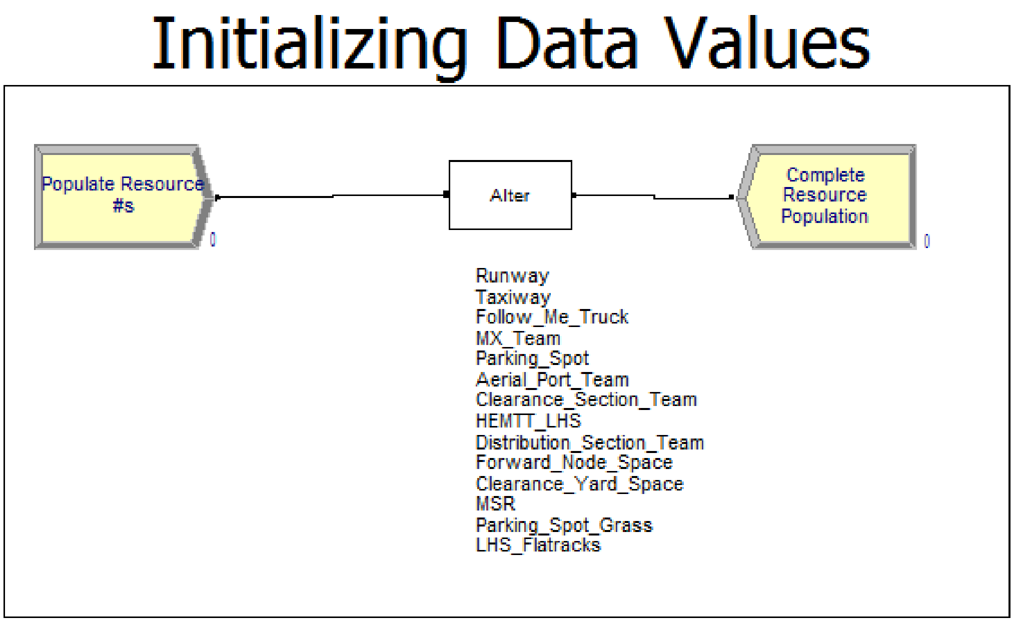


Figure 15: Initializing Data Values

Table 7: Resource Quantities

Resource	Qty
Runway	1
Taxiway	1
Follow_Me_Truck	1
MX_Team	2
Parking_Spot	10
Parking_Spot_Grass	4
Aerial_Port_Team	2
Clearance_Yard_Space	276
Clearance_Section_Team	2
HEMTT_LHS	4
LHS_Flatracks	24
MSR	Infinite
Forward_Node_Space	450
Distribution_Section_Team	2

Figure 16 identifies the beginning of the simulation where aircraft entities arrive into the system, go through a decision point that is based on the percentages of aircraft arrivals from Table 5, and pick up attributes that they will carry through the simulation. Table 8 identifies the attributes that are carried by each aircraft. Decision modules are placed immediately after each cargo carrying aircraft to ensure cargo pallet values do not exceed the aircraft capacity. Aircraft is placed on hold if aircraft parking is full and then cleared to land as parking spot resource become idle. A record module is utilized to calculate the average hold time of aircraft waiting for clearance to land.

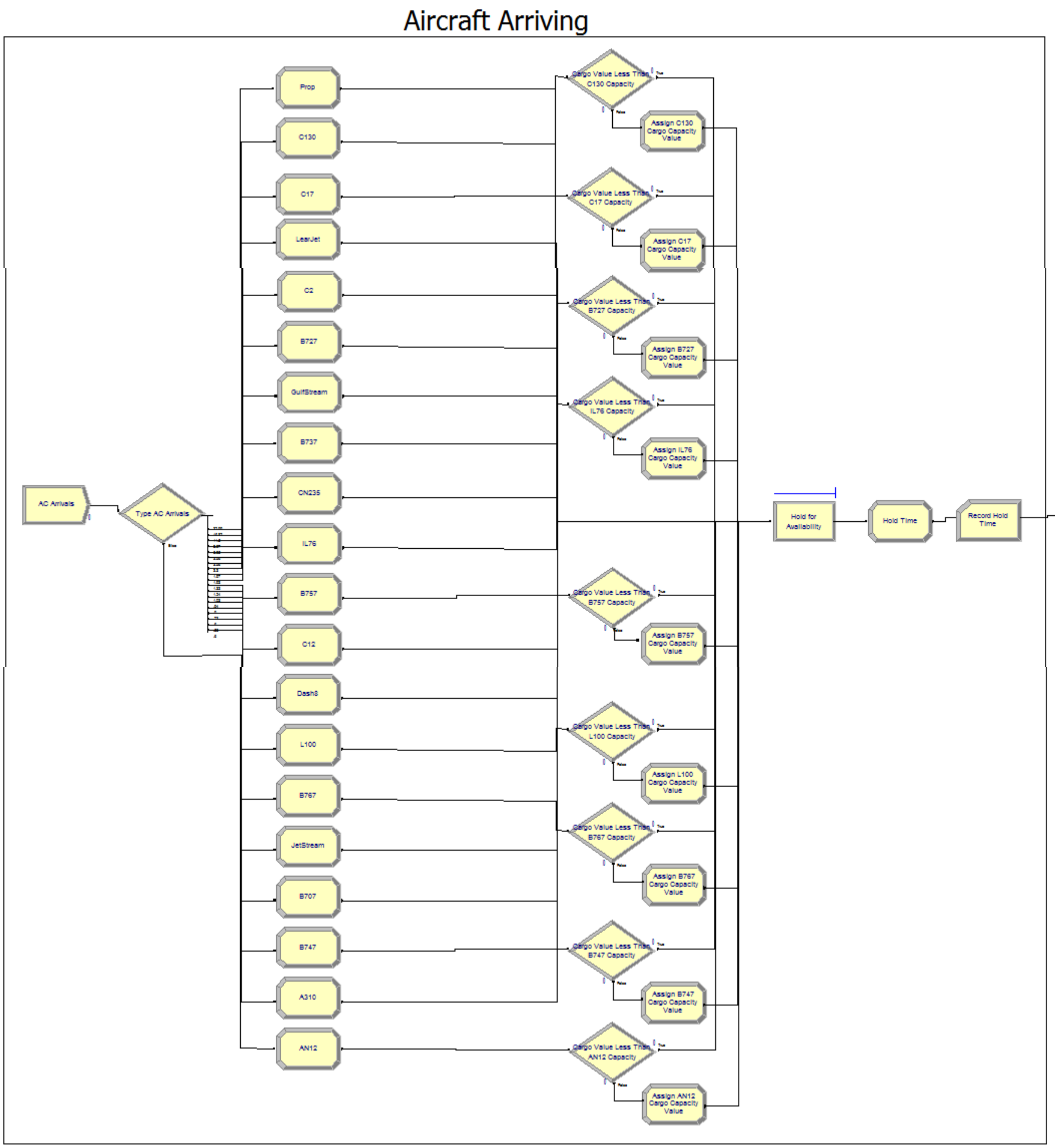


Figure 16: Aircraft Arriving

Table 8: Aircraft Attributes

Aircraft	AC_Type	Time_Of_Arrival	Service_Aircraft	Service_Zero_Cargo	AC_Cargo_Load	Zero_AC_Cargo_Load_%	Grass_Parking_%	Concrete_Parking_Size	Grass_Parking_Size	Aerial_Port_Team_Required	MX_Team_Required	Follow_Me_Required
PROP	1	TNOW	Table 11	ND	ND	100%	51.46%	0.5	0.5	0	1	1
C130	2	TNOW	Table 11	Table 12	Table 13	68.81%	NA	0.5	NA	1	1	1
C17	3	TNOW	Table 11	Table 12	Table 13	24.63%	NA	1	NA	1	1	1
LJ	4	TNOW	Table 11	ND	ND	100%	5.85%	0.5	0.5	0	1	1
C2	5	TNOW	Table 11	ND	ND	100%	0.63%	0.5	0.5	0	1	1
B727	6	TNOW	Table 11	ND	Table 13	61.45%	NA	1	NA	1	1	1
GULFSTREAM	7	TNOW	Table 11	ND	ND	100%	NA	0.5	NA	0	1	1
B737	8	TNOW	Table 11	ND	ND	100%	NA	1	NA	0	1	1
CN235	9	TNOW	Table 11	ND	ND	100%	30.43%	1	1	0	1	1
IL76	10	TNOW	Table 11	ND	Table 13	62.22%	NA	1	NA	1	1	1
B757	11	TNOW	Table 11	ND	Table 13	35.48%	3.23%	1	NA	1	1	1
C12	12	TNOW	Table 11	ND	ND	100%	3.45%	0.5	0.5	0	1	1
DASH8	13	TNOW	Table 11	ND	ND	100%	NA	1	NA	0	1	1
L100	14	TNOW	Table 11	ND	Table 13	4.55%	NA	0.5	NA	1	1	1
B767	15	TNOW	Table 11	ND	Table 13	60%	NA	1	NA	1	1	1
JETSTREAM	16	TNOW	Table 11	ND	ND	100%	18.75%	0.5	0.5	0	1	1
B707	17	TNOW	Table 11	ND	ND	100%	NA	1	NA	0	1	1
B747	18	TNOW	Table 11	ND	Table 13	7.69%	NA	1.5	NA	1	1	1
A310	19	TNOW	Table 11	ND	ND	100%	NA	1	NA	0	1	1
AN12	20	TNOW	Table 11	ND	Table 13	58.33%	NA	1	NA	1	1	1

ND = Not Documented NA = Not Applicable

Figure 17 identifies the servicing of aircraft once they are authorized to land. A Follow_Me_Truck resource meets all aircraft entities at the taxiway and directs them to aircraft parking on the concrete with an average taxi time of five minutes. Aircraft servicing is driven by the attributes that each aircraft entity carries through the simulation. A decision node separates aircraft from parking on the grass (where zero cargo is reported) or parking on the concrete (where cargo is reported) based on a percentage that aircraft entities park on the grass. Furthermore, when it has been decided for an aircraft to park on the concrete, another decision node separates the aircraft with zero cargo to download based on the attributes of that aircraft entity. Aircraft seize MX_Team resources to park and Aerial_Port_Team resources to download cargo based on an aircraft service distribution. Upon completion of aircraft servicing, the aircraft entity releases the respective resources and continues to depart the model. Table 9 identifies the resources that are seized during the servicing process. Finally, aircraft entities carrying the cargo load attribute are separated from their respective cargo, through the use of a separate module, and proceed to a cargo distribution submodel.

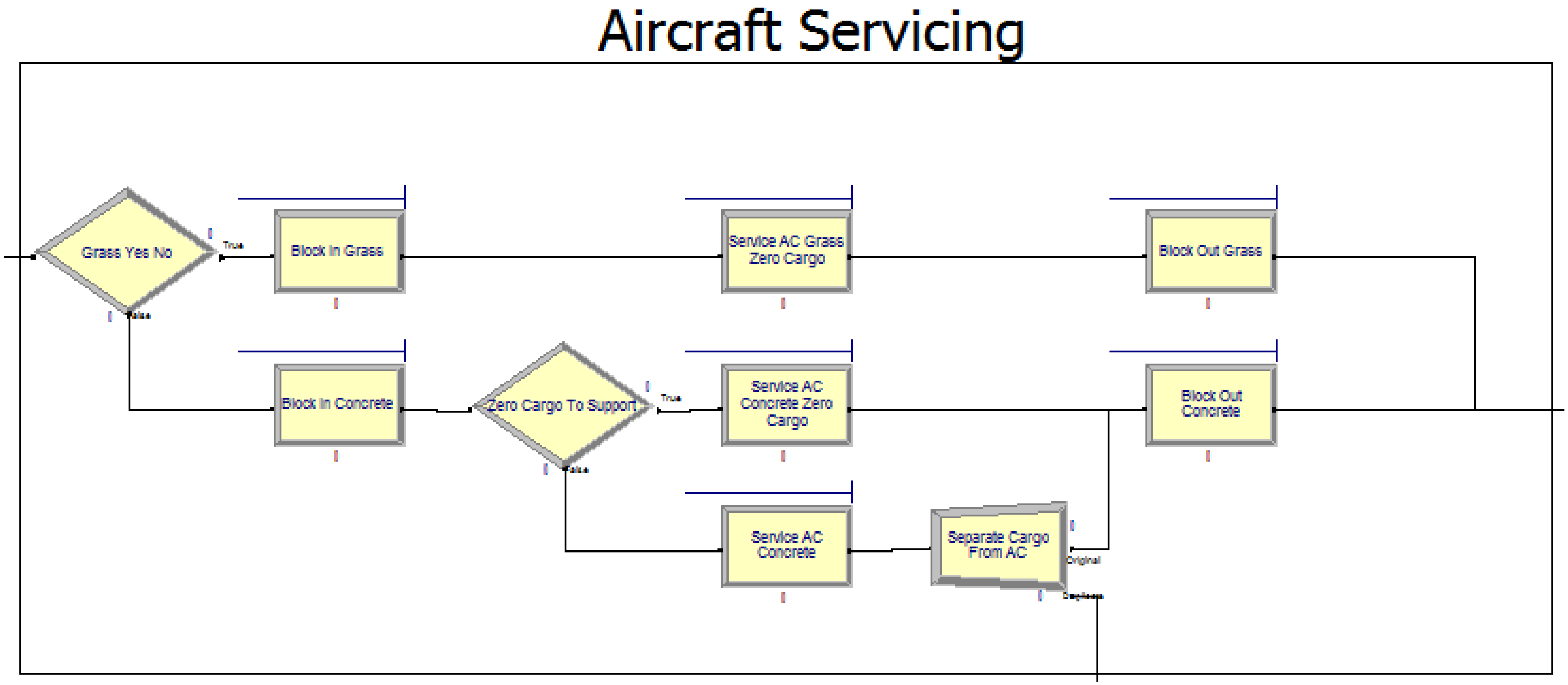


Figure 17: Aircraft Servicing

Table 9: Resources Used for Block In/Cargo Servicing/Block Out Module

Processes	**Parking_Spot**	**Parking_Spot_Grass**	**Aerial_Port_Team**	**Runway**	**Taxiway**	**Follow_Me_Truck**	**MX_Team**
Block In Grass	NA	X		X	X	NA	NA
Block In Concrete	X	NA		X	X	X	X
Service AC Grass Zero Cargo			NA				
Service AC Concrete Zero Cargo			NA				
Service AC Concrete			X				
Block Out Grass	NA	X		X	X	NA	NA
Block Out Concrete	X	NA		X	X	X	X

Figure 18 identifies the departure process for aircraft once they complete servicing within their respective locations. Statistics are collected to determine the time on station for each aircraft and its throughput before it is disposed out of the model.

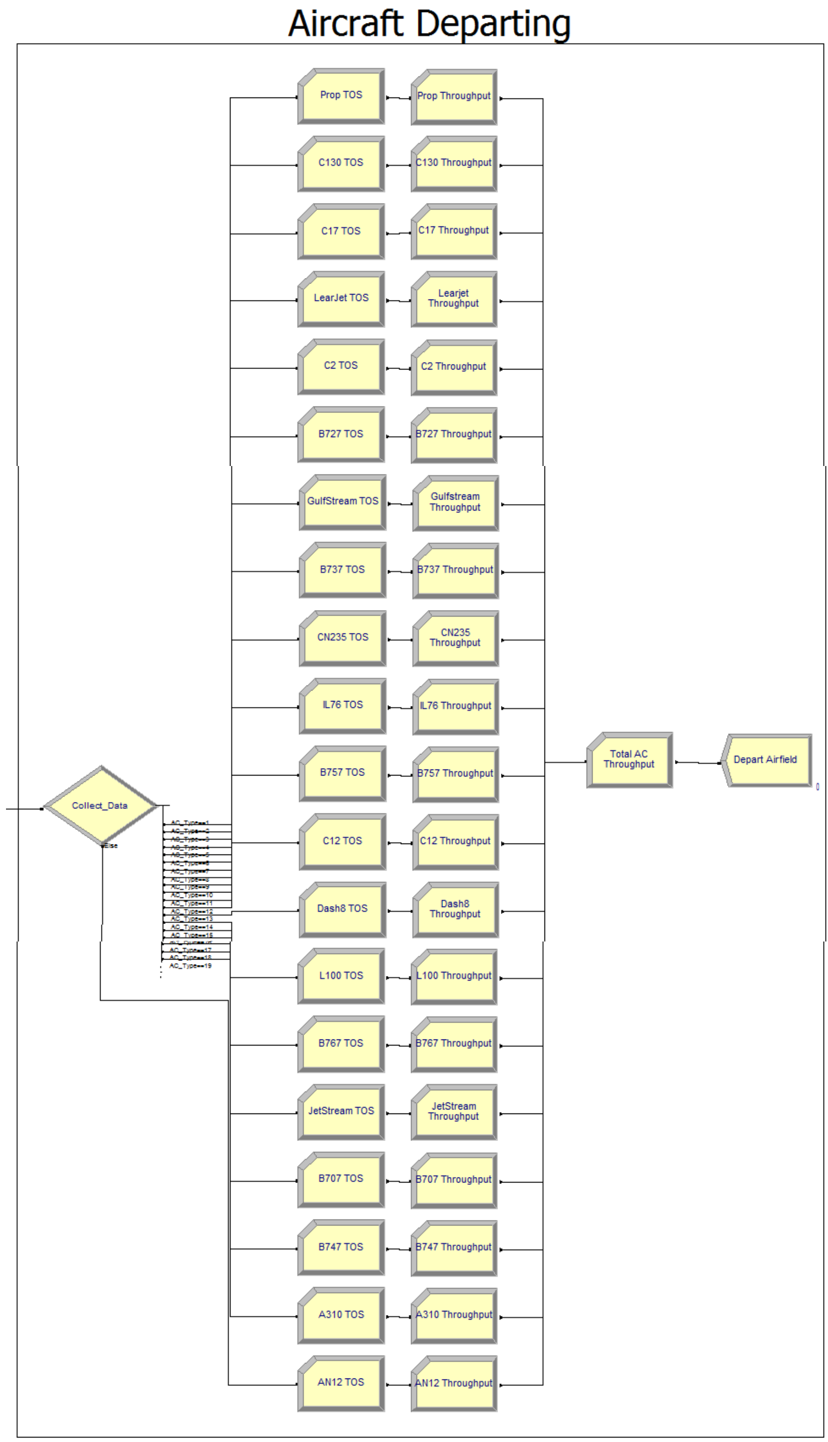


Figure 18: Aircraft Departing

Figure 19 identifies the entrance and departure of the cargo distribution submodel. Statistics are collected to calculate average cargo port-hold time (amount of time cargo is in the system) and count cargo throughput.

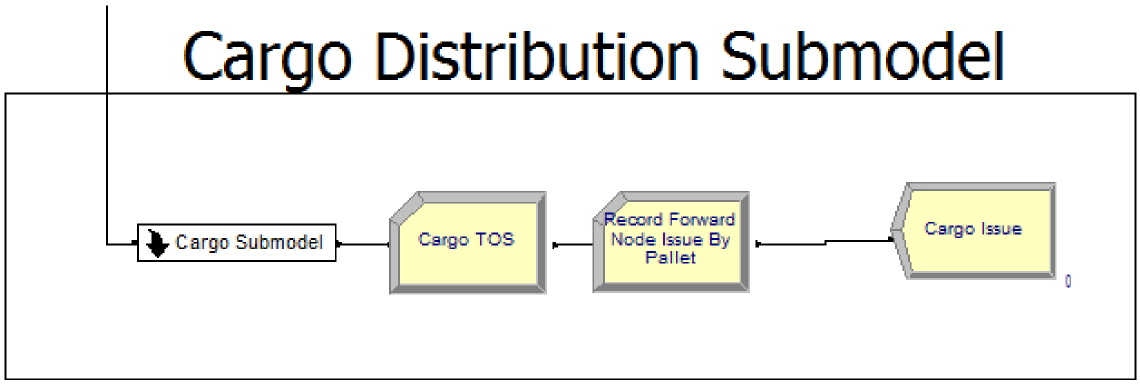


Figure 19: Cargo Distribution Submodel

Figure 20 identifies processing of cargo through the clearance yard after it is downloaded from the aircraft. The entity enters the cargo distribution submodel and immediately separates into numerous individual pallet entities based on the cargo distribution attribute of the original entity. Equation 1 identifies the mathematical algorithm used to convert the cargo weight into individual pallets. Cargo Distribution refers to the values obtained from Table 13. The % of Cargo Palletized refers to 90% of expected palletized cargo according to the JTF-PO CONOPS. Though the JTF-PO CONOPS identifies a planning weight of 4,000 pounds for palletized cargo, those numbers are used in anticipation of U.S. military cargo. Since 82% of aircraft arrivals were not U.S. military, and their cargo was built in respect to many different configurations, the Individual Pallet Weight refers to the maximum 463L pallet weight capacity of 10,000 pounds.

$$Pallets\ Per\ Aircraft = Cargo\ Distribution\left(\frac{\%\ of\ Cargo\ Palletized}{Individual\ Pallet\ Weight}\right) \tag{1}$$

Next, each entity of cargo flows through the clearance yard where it seizes a Clearance_Yard_Space resource until LHS_Flatrack and Clearance_Section_Team resources are available for use. Two pallet entities are batched together and the LHS_Flatrack resource is seized. The two pallets on the flatrack await the HEMTT_LHS resource to become available and then it is seized which culminates in the necessary resources needed for transportation to the forward node via the MSR resource. According to RPOE SMEs, the flatrack exchange occurs between 20 and 30 minutes to fully load a HEMTT with two pallets. The amount of time the MSR resource is seized is based on the calculation of the maximum speed limit allowed (15 km/h) and the distance between the clearance yard and forward node (10 km per CONOPS).

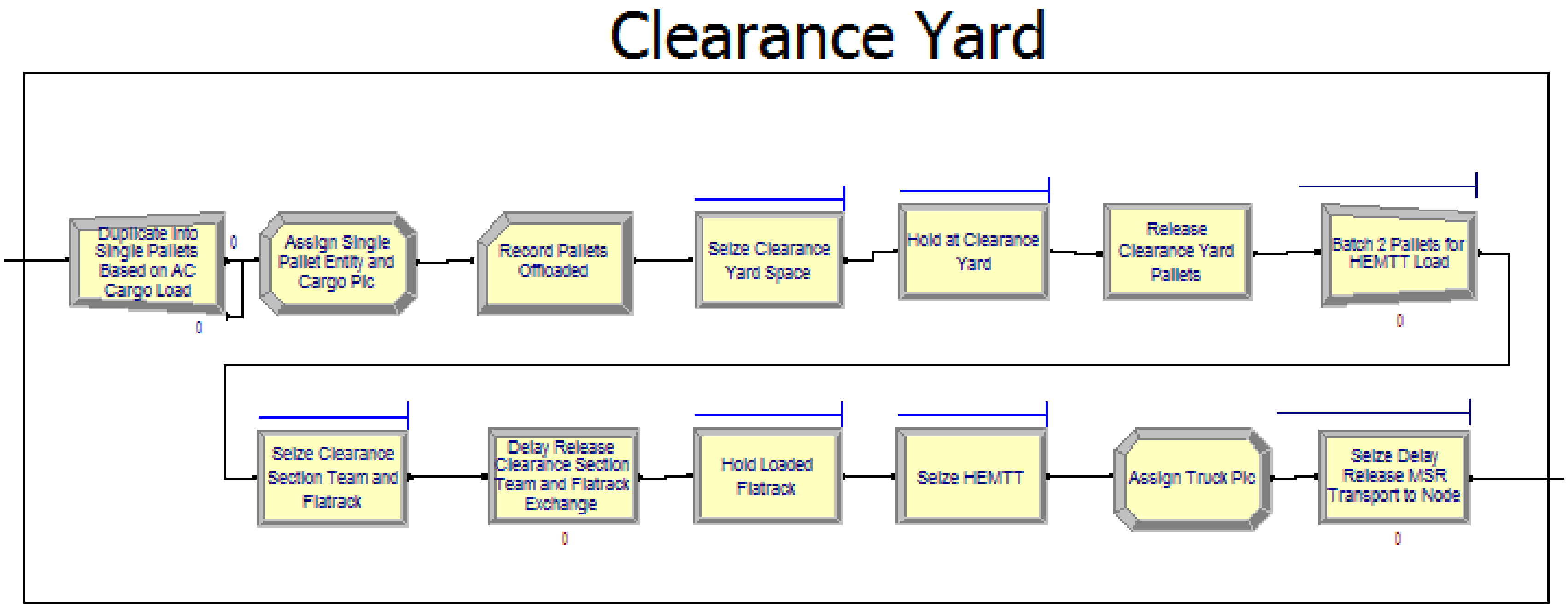


Figure 20: Cargo Distribution Submodel/Clearance Yard

Figure 21 identifies the processing of cargo through the forward node. Upon arrival of the two pallet entities and seized HEMTT_LHS and LHS_Flatrack resources the Distribution_Section_Team is seized to remove the flatrack from the HEMTT. This allows the empty HEMTT to return to the clearance yard with an empty LHS_Flatrack (as seen in Figure 22). The same flatrack exchange timeline from the clearance yard is utilized for the forward node. The batched pallet entities are separated and each seize a Forward_Node_Space resource. The Distribution_Section_Team is once again seized to load an average number of two pallets per customer truckload. For purposes of this research, the customer truckload is based on the capacity of a standard HEMTT load and has an average load time between 20 – 30 minutes according to RPOE SMEs. Each Forward_Node_Space resource is subsequently released as pallets are loaded onto the truck.

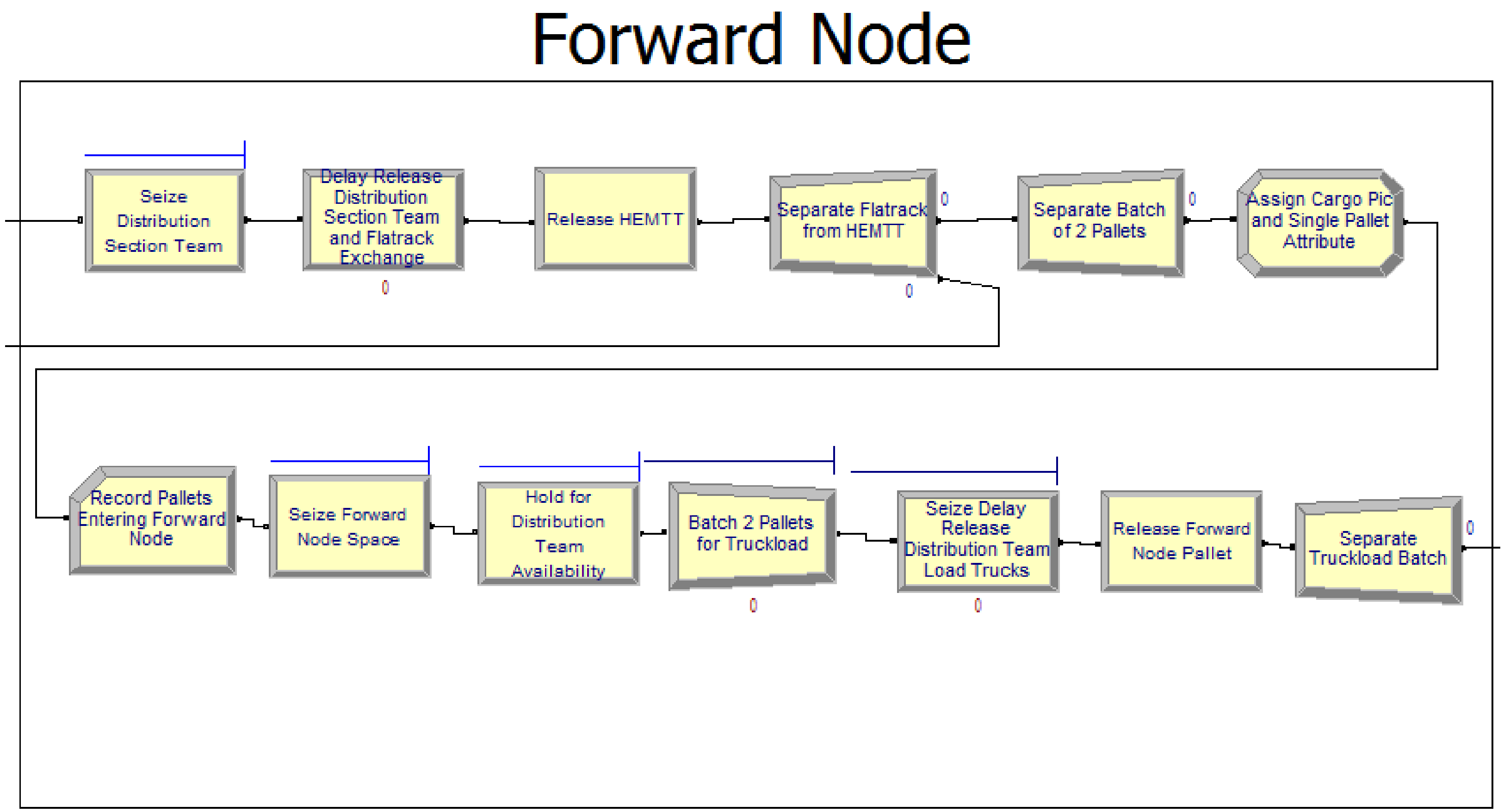


Figure 21: Cargo Distribution Submodel/Forward Node

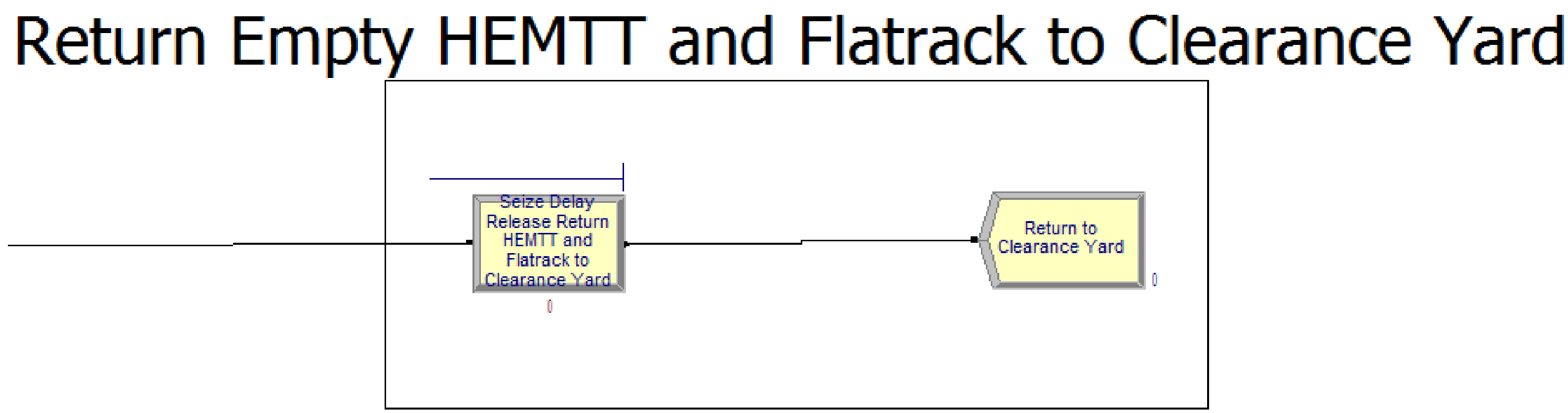


Figure 22: Return Empty LHS and Flatrack to Clearance Yard

Step 6: Verification

"Model verification is substantiating that the model is transformed from one form into another, as intended, with sufficient accuracy." (Balci, 1997) In essence, verification is building the model *correctly*. Domain and simulation SMEs are used in this research to verify the correctness of the model building. (Defense Modeling and Simulation Office, 2000) The domain SME has knowledge of the studied network flow and is needed to create a description of the conceptual model. JTF-PO SMEs are used to verify the accuracy of the JTF-PO model concept. The simulation SME has knowledge of the required simulation software to enable the developer to employ appropriate tools and techniques to accurately develop the conceptual model into a computer simulation model. The Center for Operational Analysis Lab in the Department of Operational Sciences at the Air Force Institute of Technology is used to verify the accuracy of the transformation of the model from concept to computer simulation.

In a study conducted by Stieglemeier (2006) a dynamic verification technique was used to test the decision nodes in a simulation model. The Defense Modeling and Simulation Office defined dynamic verification as a test carried out by running a model then observing its behavior. The same dynamic verification approach is utilized to assess the logical flow of entities designed to enter decision nodes that separate, duplicate, or decide a certain path. This study is concerned with the throughput of entities, thus record modules were placed immediately after each decision node to test the expected outcome against the actual outcome. Banks and others (2010), support this concept by identifying that total count statistics can give an indication of the reasonableness of the model Total count refers to the total number of items that have entered each component. Results of entity throughput are discussed in detail in Chapter 4.

Step 7: Validation

"Model validation is substantiating that the model, within its domain of applicability, behaves with satisfactory accuracy consistent with the modeling and simulation objectives." (Balci, 1997) In essence, validation is building the *correct* model. Banks and others (2010) discussed a three-step approach for validating a model from Naylor and Finger (1967). This research utilized the approach for validating the simulation.

<u>Step 1. Build a model that has high face validity:</u>

Face validity refers to a model that appears reasonable on its face to model users and others who are knowledgeable about the real system being simulated. (Banks, Carson II, Nelson, & Nicol, 2010) Through the use of SMEs and the model user, output measures are evaluated to identify model deficiencies. Furthermore, by involving the user, the perception of credibility and validity is increased which allows them to trust the use of the simulation for future decision making.

<u>Step 2. Validate model assumptions:</u>

Model assumptions fall into two categories, structural assumptions and data assumptions and were verified by SMEs from Operation UNIFIED RESPONSE. Structural assumptions involve questions of how the system operates under simplifications from reality. (Banks, Carson II, Nelson, & Nicol, 2010) Data assumptions should be based on the collection of reliable data and correct statistical analysis of the data. (Banks, Carson II, Nelson, & Nicol, 2010) Procedures for analyzing input data were completed through the use of Arena's Input Analyzer® software. Identifying the appropriate stochastic distribution, parameters and goodness-of-fit tests (through the use of Kolmogorov-Smirnoff (KS) and Chi Square (ChiSq) tests) were the results of the software and are identified in Table 10 - Table 13. The best distributions were selected based on the visual fit and the p-values $> .05$. Explanation of the use of insignificant fitted distribution ($p < .05$) is discussed in Chapter 4.

Table 10: Distribution of Collected Arrivals

Arrivals	Distribution	P-Value
Aircraft	0.999 + 672 * BETA(0.323, 12.5, 1)	(KS) P < .01

Table 11: Distributions of Collected Aircraft Service Data

AC Type	Service Aircraft Distributions	P-Value
PROP	0.999 + GAMM(31.8, 1.77, 2)	(KS) P > .15
C130	3 + WEIB(95.4, 1.9, 3)	(KS) P > .15
C17	13 + GAMM(30.8, 3.19, 4)	(KS) P > .15
LJ	2 + WEIB(63.6, 1.44, 5)	(KS) P > .15
C2	1.5 + LOGN(14.6, 9, 6)	(ChiSq) P < .005
B727	30 + WEIB(102, 1.64, 7)	(KS) P > .15
GULFSTREAM	7 + WEIB(65.4, 1.67, 8)	(KS) P > .15
B737	27 + WEIB(107, 1.6, 9)	(KS) P > .15
CN235	26 + WEIB(65.1, 1.36, 10)	(KS) P > .15
IL76	58 + WEIB(87.8, 1.03, 11)	(KS) P > .15
B757	69 + 156 * BETA(1.65, 2.61, 12)	(KS) P > .15
C12	6 + EXPO(39.7, 13)	(KS) P > .15
DASH8	35 + 162 * BETA(1.31, 2.6, 14)	(KS) P > .15
L100	48 + 158 * BETA(1.05, 1.67, 15)	(KS) P > .15
B767	65 + 289 * BETA(1.12, 2.03, 16)	(KS) P > .15
JETSTREAM	UNIF(12.5, 91.5, 17)	Not Reported
B707	UNIF(59, 291, 18)	(KS) P > .15
B747	UNIF(113, 308, 19)	(KS) P > .15
A310	TRIA(109, 193, 243, 20)	(KS) P > .15
AN12	TRIA(87, 101, 250, 21)	(KS) P > .15

Table 12: Distributions of Collected Zero Cargo Aircraft Service Data

AC Type	Service Zero Cargo Distributions	P-Value
C130	TRIA(61, 118, 180, 22)	(KS) P > .15
C17	65 + WEIB(77.5, 0.891, 23)	(KS) P > .15

Table 13: Distributions of Collected Aircraft Cargo Data

AC Type	Aircraft/Cargo Weight Distributions	P-Value
C130	NORM(1.23e+004, 8.62e+003, 24)	(KS) P < .01
C17	-0.001 + LOGN(2.34e+013, 2.13e+023, 25)	(KS) P < .01
B727	NORM(3.3e+004, 1.62e+004, 26)	(KS) P > .15
IL76	TRIA(1.5e+004, 6.75e+004, 9e+004, 27)	(KS) P > .15
B757	NORM(4.76e+004, 3.02e+004, 28)	(KS) P > .15
L100	TRIA(1e+004, 3e+004, 5e+004, 29)	(KS) P > .15
B767	-0.001 + EXPO(4.59e+004, 30)	(KS) P > .15
B747	UNIF(4.5e+004, 2.21e+005, 31)	(KS) P > .15
AN12	UNIF(1.5e+004, 3.27e+004, 32)	(KS) P > .15

Step 3. Compare input/output transformations with historical data:

The third and final step in the validation will result in comparing the output data from the simulation with the collected data sets. More detail in the validation will be discussed in Chapter 4.

Step 8: Experimental Design

In this step, alternatives to the model that are to be simulated must be determined for experimentation. (Banks, Carson II, Nelson, & Nicol, 2010) This study uses Design of Experiments (DOE) to plan the statistical experimentation in an efficient scientific approach. DOE refers to the process of planning the experiment so that appropriate data will be collected and analyzed by statistical methods, resulting in valid and objective conclusions.

Factorial designs are widely used to experiment the response of several factors in a study. (Montgomery, 2009) The aim of this study is to report four responses based on the four treatments of two factors. This results in a 2 factorial design. Each level of the factors are labeled low (-) or high (+). The objective of the experiment is to determine how adjustments to either of the two factors would affect the response. (Montgomery, 2009)

In order to obtain enough point estimate values to support the central limit theorem ($n \geq 30$), 30 simulated replications will be completed. An analysis of variance (ANOVA) will be used to calculate statistical differences between the mean values of the point estimators from each response. A visual depiction of the experimental plan is shown in Figure 23.

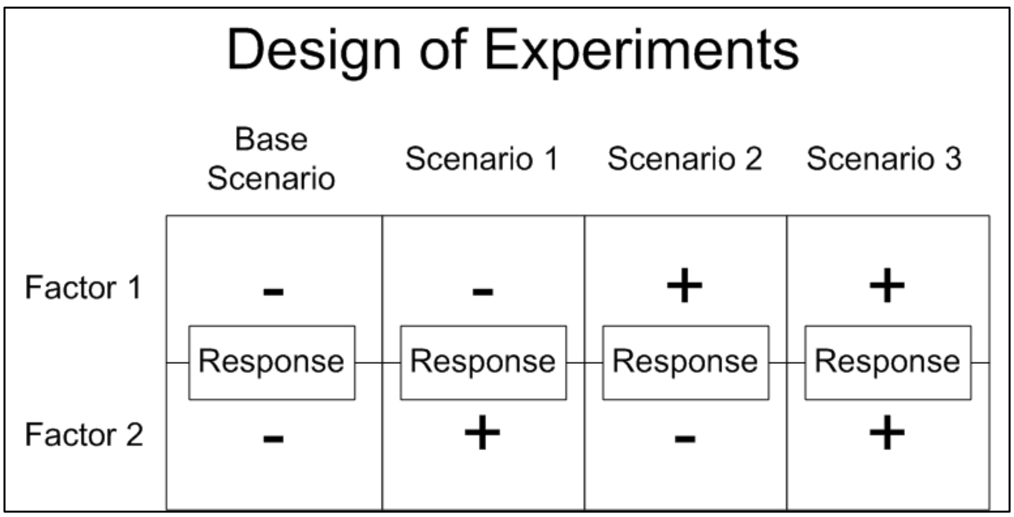


Figure 23: Design of Experiments

In order to reduce variance in the point estimators, Common Random Number (CRN) streams are used for each statistical distribution. CRN means that, for each replication, the same stream of random numbers is used to simulate each system. The purpose of using CRN is to introduce a positive correlation between the point estimates of each replication. This achieves a variance reduction in the mean difference between the point estimators. (Banks, Carson II, Nelson, & Nicol, 2010) More detail in the experimental design will be discussed in Chapter 4.

Step 9: Production Runs and Analysis

This step is the execution of the simulation model and analysis of its output. (Banks, Carson II, Nelson, & Nicol, 2010) More detail in the analysis and design will be discussed in Chapter 4.

Step 10: More Runs?

Given the analysis of runs completed for this thesis, more runs will be determined by the user of the model. The user will determine additional developments of experimental designs and execute them as appropriate.

Step 11: Documentation and Reporting

This thesis serves as the documentation and reporting of the development of this simulation model.

Step 12: Implementation

The objective of this simulation model is for it to be used for future decision making in JTF-PO operations conducting HA/DR missions. Upon completion of this thesis, the model will be delivered to the user for implementation.

Conclusion

This chapter explained the methodology used to develop the simulation model for evaluating the Joint Task Force-Port Opening operation in HA/DR environments. The first section defined simulation and identified when it should not be attempted to model systems. The next section identified the overarching requirements of building models in a defense logistics network. This was followed by a brief introduction to the method of discrete-event simulation. Next, a definition of simulation terms was introduced in order to provide a framework of understanding discrete-event simulation with Arena® software. Finally, the twelve-step process of simulation model building was introduced and accompanied by a detailed description of the use of each step in the author's research effort.

IV. Analysis and Results

Introduction

This chapter begins by recapturing the assumptions, limitations and observations of the JTF-PO simulation model. The next sections validates the model by comparing its output measures against the output measures retrieved from Operation UNIFIED RESPONSE in order to compare the simulation model's resemblance of real world operations. The next section analyzes the experimental design and conducts statistical testing to determine differences between experiments. Finally, the chapter ends with results to answer the investigative questions and research question.

Prior to model validation, a recount of the assumptions, limitations and observations are presented again in order to solidify the understanding of the boundaries of the model.

Assumptions/Limitations/Observations

The model created for this research is built upon assumptions derived from Department of Defense Regulations, JTF-PO subject matter experts (SMEs) and the data collected from the Operation UNIFIED RESPONSE after action report (AAR) in Port-au-Prince, Haiti 16 January – 17 February 2010.

Assumptions

1. Operation UNIFIED RESPONSE aircraft arrivals rates and times are representative of future scenarios.
2. 90% of all cargo is palletized at 10,000 pounds each.
3. All palletized cargo is loaded on the standard military 463L pallet.

4. Missing aircraft cargo data is treated as an empty aircraft.
5. No known delays in aircraft ground handling, or cargo distribution were annotated and are assumed out of the model.
6. Service times for aircraft are calculated as the difference between the arrival and departure of all aircraft.
7. Individual actions within the timeframe of aircraft servicing were not captured and therefore assumed to be factored into the service times. They are as follows, aerial port teams' transportation to aircraft, amount of time to download cargo, transport of cargo from aircraft to clearance yard, and any required upload of passengers or cargo.
8. All cargo is destined to the final staging point at the Forward Node.
9. Transport time of taxiing aircraft is held at a constant five minutes.
10. The main supply route is 10 kilometers long.
11. Truck speed on the main supply route is 15 kilometers per hour.
12. Transport time on the main supply route is 40 minutes one way between clearance yard and forward node.
13. Trucks are available at all times to receive cargo at the distribution point.
14. Trucks used by the customers have the same characteristics as the Heavy Expanded Mobility Tactical Truck (HEMTT).
15. Customer trucks take a standard 20 – 30 minutes to load.

Limitations

1. The model only captures the offload and distribution of cargo and does not capture any upload operations.

2. The model remains within the bounds of the JTF-PO operation from aircraft arrival to distribution of cargo.
3. The model does not consider cargo issued from the clearance yard.
4. The model does not consider passenger processing operations.

Observations

1. High fidelity of aircraft arrival data from AAR:

   Of the 3,006 reported aircraft arrivals in 37 days, 2,561 arrivals in 32 days were recorded (85% of reported missions on the after action report).

2. High fidelity of aircraft service times with n > 12 arrivals into the location:

   Of the 2,561 arrivals into the location, 94 different aircraft types were recorded. Any aircraft that arrived more than 12 times, and were recorded as being serviced, were selected to use in the simulation. This resulted in a sampling of the top 20 aircraft with an overall n = 2,300 arrivals serviced (99% of collected aircraft arrival data).

3. Moderate fidelity of aircraft cargo weight data collected from aircraft service times:

   Of the 2,300 aircraft serviced, 882 aircraft were identified as cargo carrying aircraft; 516 of those aircraft were recorded with cargo weight data (59% of collected cargo aircraft service data).

4. 82% of aircraft arrived via US commercial or international thus a majority of the cargo was not in the traditional 463L pallet configuration. Cargo arrived loose, civilian pallet sized (1.5 times larger than the 463L pallet) or warehouse

skid configuration. For reporting, all cargo was converted to a 463L equivalent pallet.

Model Validation

The model validation consists of examining the insignificant distribution fits in the model and simulating Operation UNIFIED RESPONSE in order to measure its offload of cargo and throughput of aircraft in the system. Using the stochastic distributions identified in Table 10 - Table 13, the resources identified in Table 14, the operation was simulated under 30 replications for 32 days. The simulation results will be compared to the results of reality to determine if the model is a valid representation of the real world.

Table 14: Haiti Resource Quantities

Resource	Qty
Runway	1
Taxiway	1
Follow_Me_Truck	1
MX_Team	2
Parking_Spot	10
Parking_Spot_Grass	4
Aerial_Port_Team	2 - 5*
Clearance_Yard_Space	276
Clearance_Section_Team	2
HEMTT_LHS	4
LHS_Flatracks	24
MSR	Infinite
Forward_Node_Space	450
Distribution_Section_Team	2

*Note: Aerial_Port_Team capacity started at 2 then increased to 5 on 21 January 2010 per AAR.

Table 15 identifies the comparison of real world aircraft throughput from the collected data with the simulation aircraft throughput. A difference of 17 arrivals indicates the simulation is collecting .66% below the real world aircraft arrivals. Furthermore, Figure 24 identifies a visual fit of the beta distribution to warrant its use. A close look at the data suggests the reason for the lack of fit may be due to the large number of inter-arrivals times (n = 2,561) used to test for distribution significance. Taken all together, the distribution is a valid fit.

Table 15: Aircraft Throughput Comparison

Real World Qty Throughput	**Sim Qty Throughput**	**Diff**	**% Diff**
2,561	2,578	+17	+0.66%

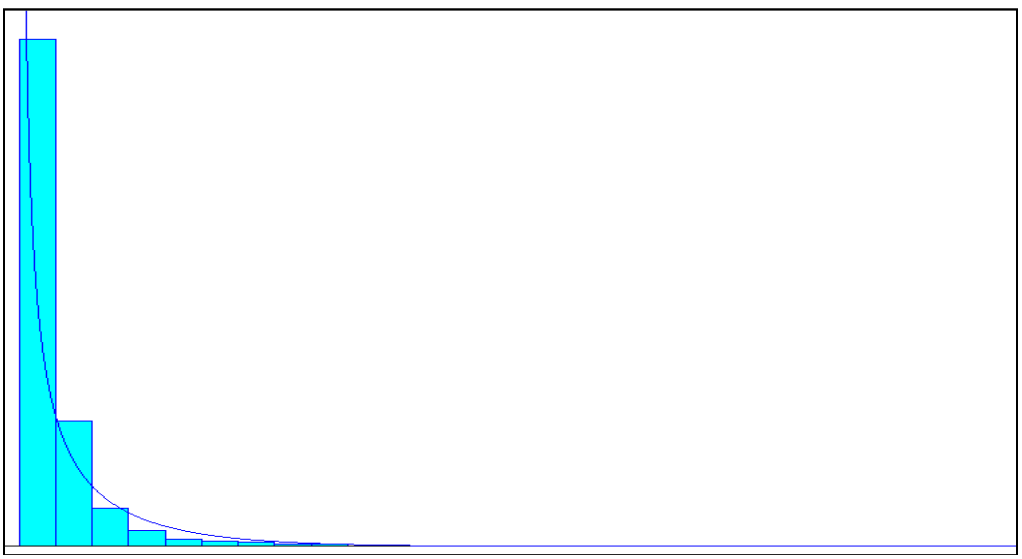


Figure 24: Aircraft Arrival Beta Distribution Fit

Figure 25 and Figure 26 identifies the visual distribution fit for C2 and Jetstream aircraft service times. Visually, the distribution suggests they are a valid fit for simulation purposes. A close look at the data suggests the lack-of-fit is due to the extreme spikes in the histogram.

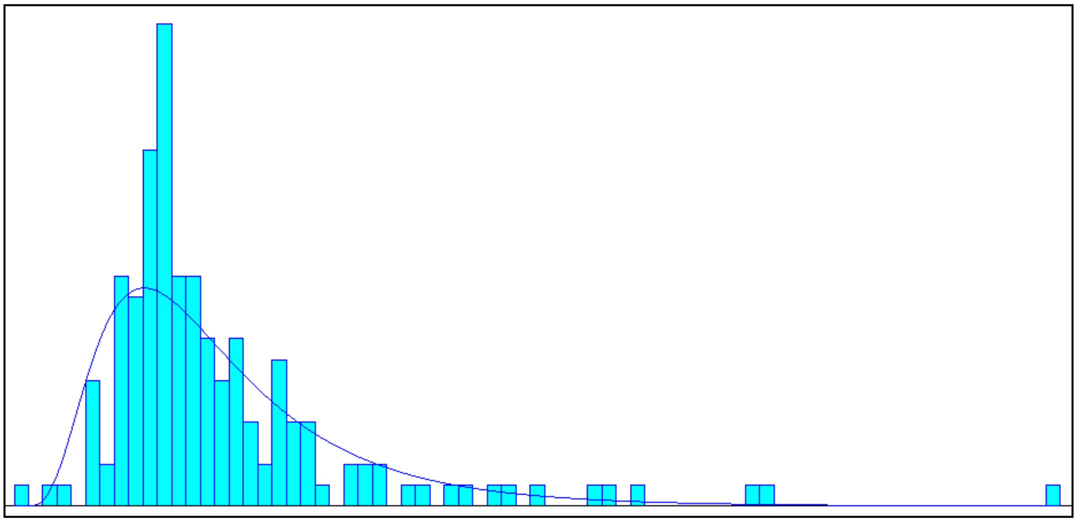


Figure 25: C2 Service Lognormal Distribution Fit

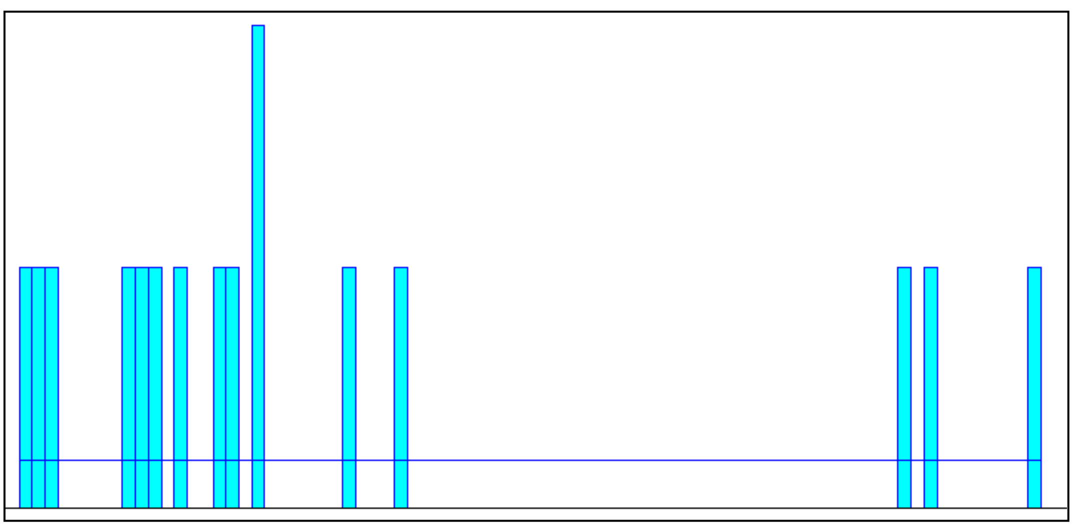


Figure 26: Jetstream Service Uniform Distribution Fit

Though C-130 and C-17 cargo weight distributions resulted in insignificant values in Table 13 ($p < .05$), Table 16 identifies the pallet offload comparison between collected real world output and simulated output are a valid representation. Figure 27 suggests a visual fit for C-130 aircraft but Figure 28 suggests otherwise for C-17 aircraft. A close look at the data suggests that the reason for a lack-of-fit may be due to the large number of aircraft with zero cargo reported. According to an article written by Schmeiser, (1999), goodness-of-fit tests deal with statistical significance and not practical significance. He mentions further that a modeler should not focus on whether the input is absolutely correct, but whether it is adequate for the analysis at hand. The fallacy of the test is made obvious when there is a large real world data set used which yields a larger power and the error in the model becomes statistically significant. Conceptually, the results in Table 16 assume otherwise. Analysis of other distribution fits resulted in the best distribution fit for C-130 and C-17 aircraft are the ones identified in Table 13.

Table 16: Pallet Offload Comparison

AC Type	Real World Qty/Plts	Sim Qty/Plts	Diff Qty/Plts	% Diff
C130	175	148	-27	-15%
C17	1,306	1,382	+76	+5%

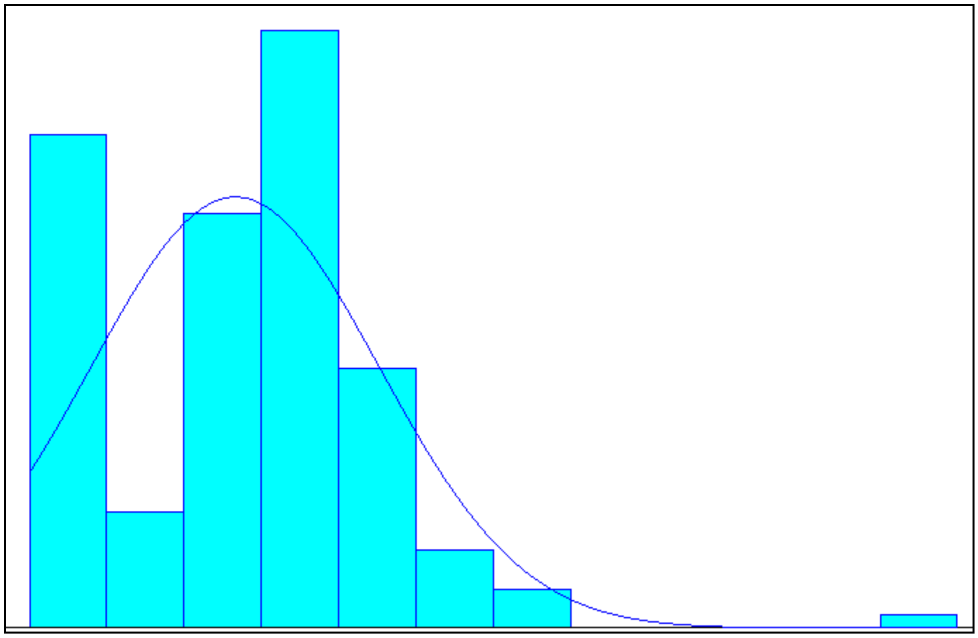


Figure 27: C130 Cargo Normal Distribution Fit

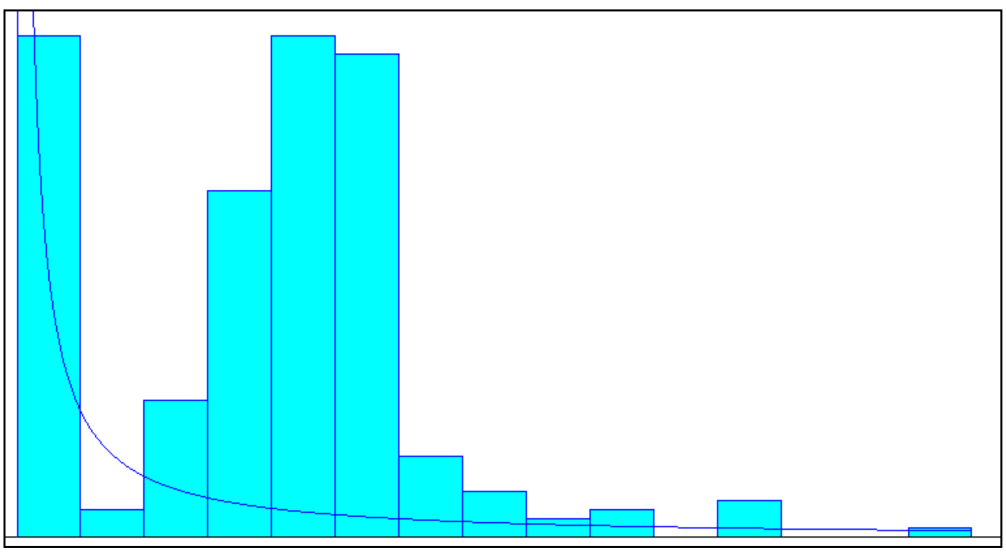


Figure 28: C17 Cargo Lognormal Distribution Fit

The results of the model validation are identified in Table 17. The real world column identifies the number of aircraft arrivals and cargo offload collected for 32 days

(17 Jan – 17 Feb 2010). The simulation column identifies aircraft arrivals and cargo offload from 30 replications of 32 days (17 Jan – 17 Feb 2010) using a stochastic aircraft arrival distribution. A difference of 18 arrivals indicates the simulation is collecting 1% above the documented aircraft arrivals in the operation. A difference of 58 pallets indicates the simulation is capturing 3% above the reported cargo offloaded.

Table 17: JTF-PO Simulation Validation Results

	Real World	Simulation	Difference	Percentage Difference
Aircraft Throughput	*2,561	2,579	+18	+1%
Pallet Offload	*2,014	2,072	+58	+3%

*Collected from Operation UNIFIED RESPONSE data set.

A 95% confidence interval was calculated around the simulation output to determine if the real world totals were captured within the lower and upper bounds of the its limits (Table 18, Figure 29 and Figure 30). The results indicate that the Real World Aircraft Throughput and Pallet Offload do fall within the limits of the simulated results. This indicates that the model makes valid representation of the real world data provided by the SMEs. The next step will be to conduct further experimental testing to determine the best-case scenario for future JTF-PO missions by adjusting the Working and Distribution MOG resources.

Table 18: Haiti Simulation 95% Confidence Interval Statistics

	Average	Std Dev	Lower Confidence Limit	Upper Confidence Limit	Min	Max
Aircraft Throughput	2,579	74	2,552	2,609	2,440	2,710
Pallet Offload	2,072	180	2,005	2,139	1,740	2,450

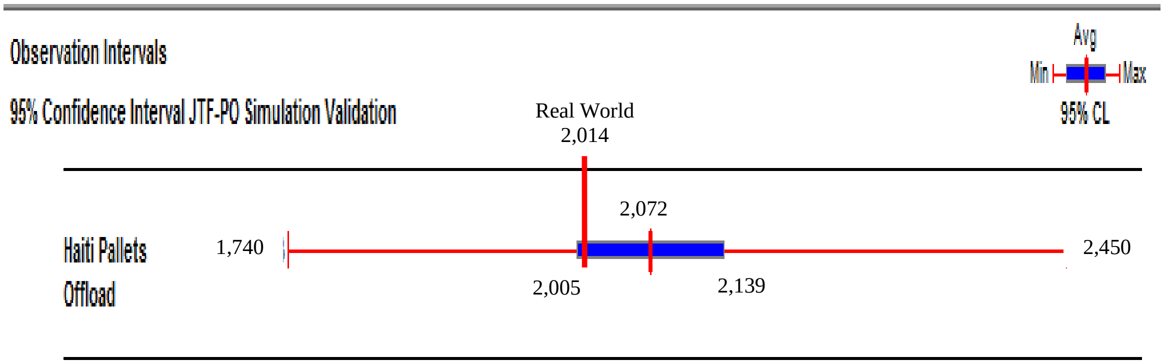


Figure 29: Haiti Simulation Pallets Offloaded Confidence Interval

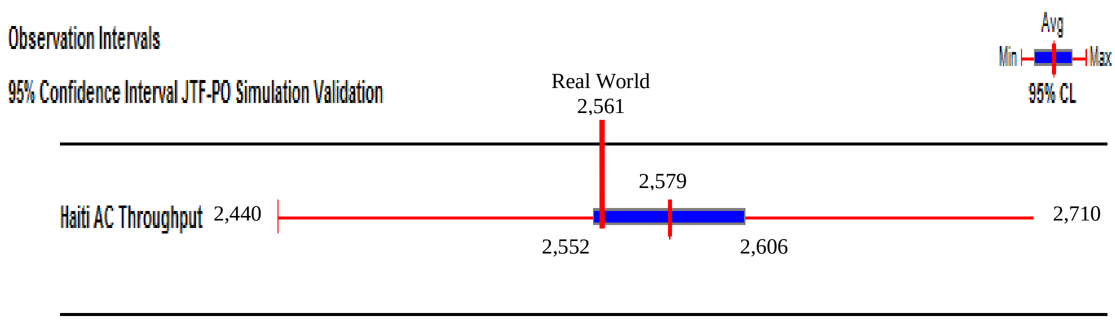


Figure 30: Haiti Simulation Aircraft Throughput Confidence Interval

Analysis of Experimental Design

The experimental design serves the purpose to provides the user insight into the best mix of resources that will maximize the point estimators of cargo throughput in a HA/DR environment. Figure 31 identifies the 2 factorial design to use in this research. The design consists of factors, levels, responses, and scenarios. The factors are categorized into two areas, Working MOG and Distribution MOG. The Working MOG consists of the Aerial_Port_Team resources and the Distribution MOG consists of the Distribution_Section_Team resources. The levels represent the four combinations of resources that each factor will utilize in the scenarios. The responses represent the average cargo throughput to expect for each experiment. The scenarios are categorized into four experiments, CONOPS, DOE1, DOE2 and DOE3. The CONOPS scenario represents the baseline number of resources used for planning according to the JTF-PO Concept of Operations. The subsequent scenario, DOE1 – DOE3, represent the combination of resources each factor will utilize.

In order to check the robustness of the simulation model, a form of sensitivity analysis is performed to test the relationship between factors and responses. Sensitivity analysis is the investigation of potential changes and errors in parameter values and assumptions and there impacts on conclusions to be drawn from the model. (Pannell, 1996) For experimental purposes, the time between aircraft arrivals is cut in half in order to double the aircraft arrival rate into the system. This procedure allows the model to run at a higher capacity and test the robustness of an optimal cargo throughput solution. Furthermore, this supports the decision maker’s ability to make correct decisions about how to increase cargo throughput.

To address the investigative questions, the four experiments were modeled in order to obtain valid conclusions. The CONOPS model is the response to investigative question IQ1, DOE1 and DOE3 models are the response to investigative question IQ2, and DOE2 and DOE3 models are the response to investigative question IQ3.

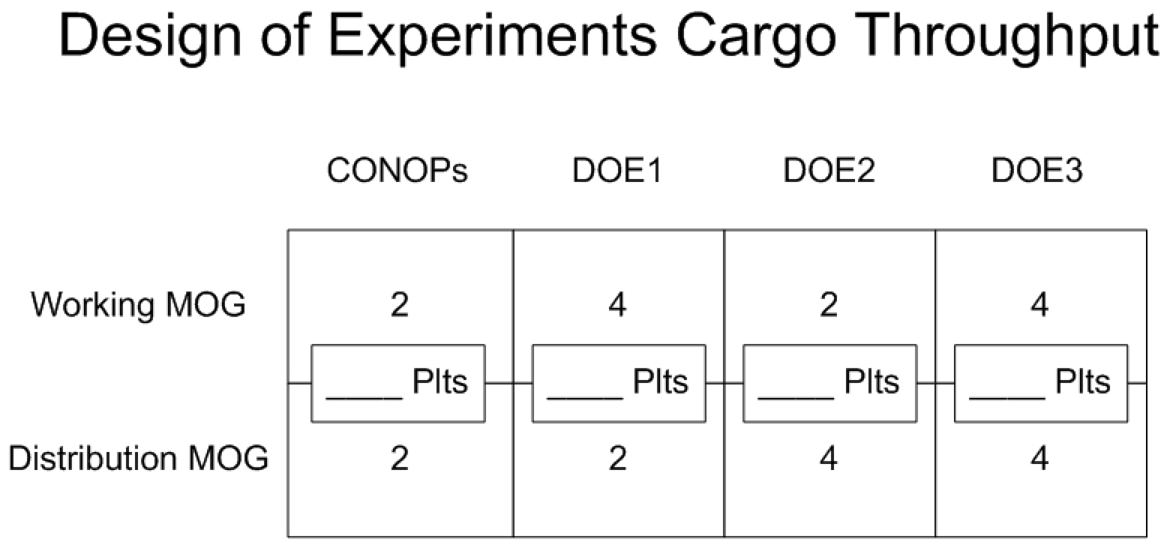


Figure 31: Design of Experiments Cargo Throughput

CONOPS Experiment:

The CONOPS experiment was designed as a baseline model, defined by the Concept of Operations for the JTF-PO, to measure against all other experimental designs. A working MOG of two aircraft and Distribution MOG of two trucks are the two factors of interest in the model and are represented as Aerial_Port_Team and Distribution_Section_Team resources, respectively. After adjusting the values of the resources and running the model for 30 replications, the results of the experiment indicate 2,935 pallet throughputs. Additional statistics indicate a 99% utilization rate on the Aerial_Port_Team and 80% utilization rate on the Distribution_Section_Team.

DOE1 Experiment:

The DOE1 experiment was designed as the first model to determine changes in throughput by adjusting the working MOG to four and holding the Distribution MOG constant at the baseline two. After adjusting the values of the resources and running the model for 30 replications, the results of the experiment indicate an increase of 64 pallets for a throughput of 2,999 pallets. Additional statistics indicate a 47% reduction in utilization rate to 52% on the Aerial_Port_Team and a steady utilization rate of 81% on the Distribution_Section_Team.

DOE2 Experiment:

The DOE2 experiment was designed as the second model to determine changes in throughput by adjusting the Distribution MOG to four and holding the Working MOG constant at the baseline two. After adjusting the values of the resources and running the model for 30 replications, the results of the experiment indicate an increase of 87 pallets for a throughput of 3,022 pallets. Additional statistics indicate a steady utilization rate of 99% on the Aerial_Port_Team and a 49% reduction in utilization rate to 41% on the Distribution_Section_Team.

DOE3 Experiment:

The DOE3 experiment was designed as the third model to determine changes in throughput by adjusting the Distribution MOG and the Working MOG to four. After adjusting the values of the resources and running the model for 30 replications, the results of the experiment indicate an increase of 264 pallets for a throughput of 3,199 pallets. Additional statistics indicate a 47% reduction in utilization rate to 53% on the Aerial_Port_Team and a 46% reduction in utilization rate to 43% on the Distribution_Section_Team.

The results of each of the experiments are summarized in Figure 32 and Figure 33.

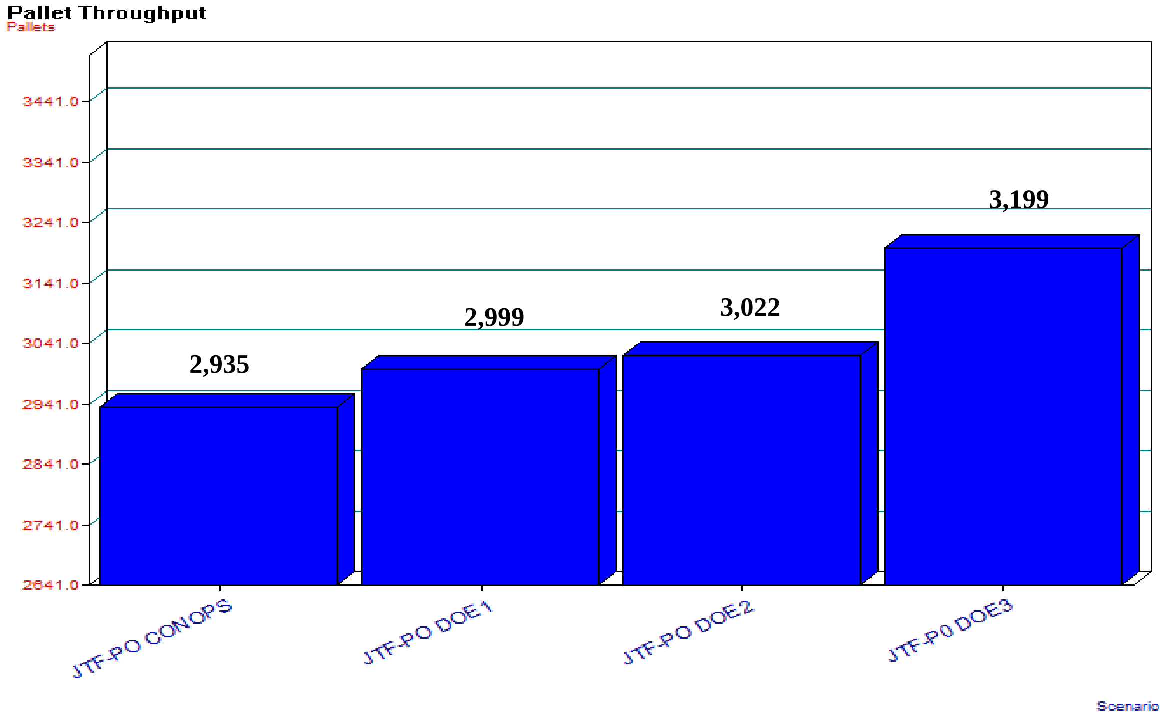


Figure 32: Pallet Issue Per Scenario

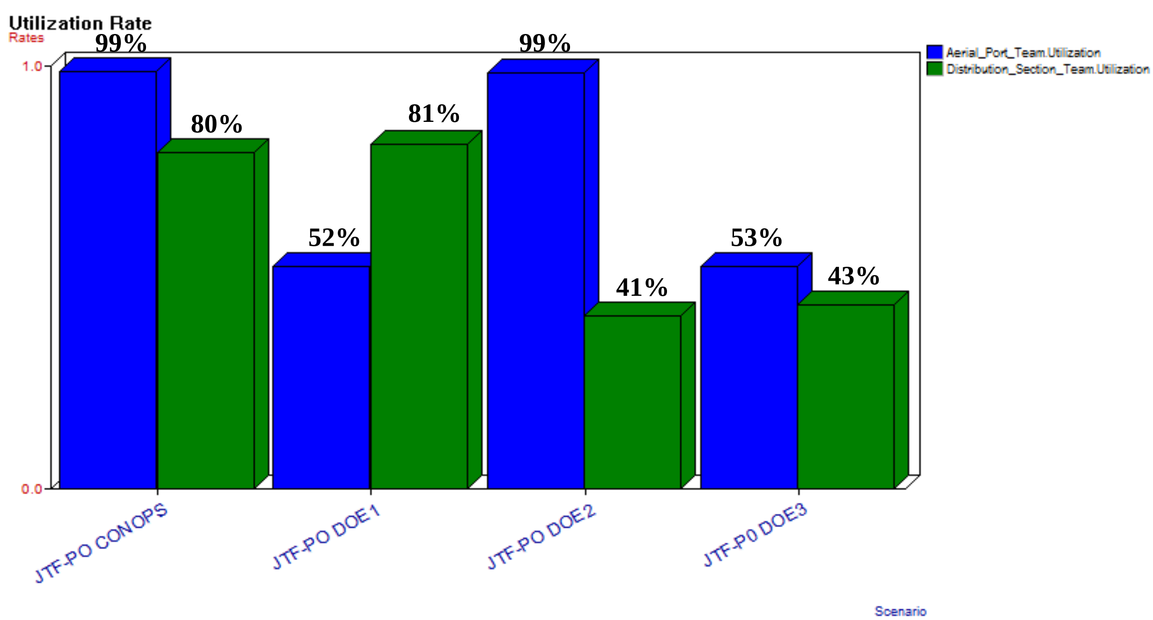


Figure 33: Resource Utilization Rate Per Scenario

An ANOVA test was conducted in Design Expert®. The ANOVA compares the effect of Working and Distribution MOG resources on cargo throughput under the conditions of baseline Working and Distribution MOG (CONOPS), increased Working MOG (DOE1), increased Distribution MOG (DOE2), and increased Working and Distribution MOG (DOE3). The initial ANOVA summary in Table 19 identifies that there was a significant difference between the effects of Working and Distribution MOG resources at the 5% level ($p < .05$) for the experiments [$F(df = 3) = 22.42$, $p < .0001$]. The interaction between MOGs resulted in no significant effect on the model and is removed to show an improved ANOVA summary in Table 20.

Table 19: Initial ANOVA Summary

Analysis Of Variance Table [Partial sum of squares - Type III]						
Source	**Sum of Squares**	**df**	**Mean Square**	**F Value**	**P-Value**	
Model	1,144,615	3	381,538.2	22.42	< 0.0001	Significant
A-Working MOG	432,240	1	432,240	25.4	< 0.0001	Significant
B-Distribution MOG	615,473.6	1	615,473.6	36.18	< 0.0001	Significant
AB	96,900.83	1	96,900.83	5.69	0.02	Not Significant
Pure Error	1,973,960	116	17,016.9			

Table 20: Improved ANOVA Summary

Improved Analysis Of Variance table [Partial sum of squares - Type III]						
Source	**Sum of Squares**	**df**	**Mean Square**	**F Value**	**P-Value**	
Model	1,047,714	2	523,856.8	29.59699	< 0.0001	Significant
A-Working MOG	432,240	1	432,240	24.4208	< 0.0001	Significant
B-Distribution MOG	615,473.6	1	615,473.6	34.77318	< 0.0001	Significant
Residual	2,070,861	117	17,699.66			
Pure Error	1,973,960	116	17,016.9			

A comparison of means is identified in Figure 34 and indicates that there appears to be significant differences between CONOPS (M = 2,935, SD = 91), DOE2 (M = 3,022, SD = 121) and DOE3 (M = 3,199, SD = 155). Furthermore, DOE1 (M = 2,999, SD = 145) appears to not significantly differ from CONOPS and DOE2. Finally, DOE3 appears to exhibit the only significant difference between all other remaining scenarios. Taken together, these results suggest that an increase in Working and Distribution MOG resources (DOE3) resulted in a significant difference in the effect on cargo throughput.

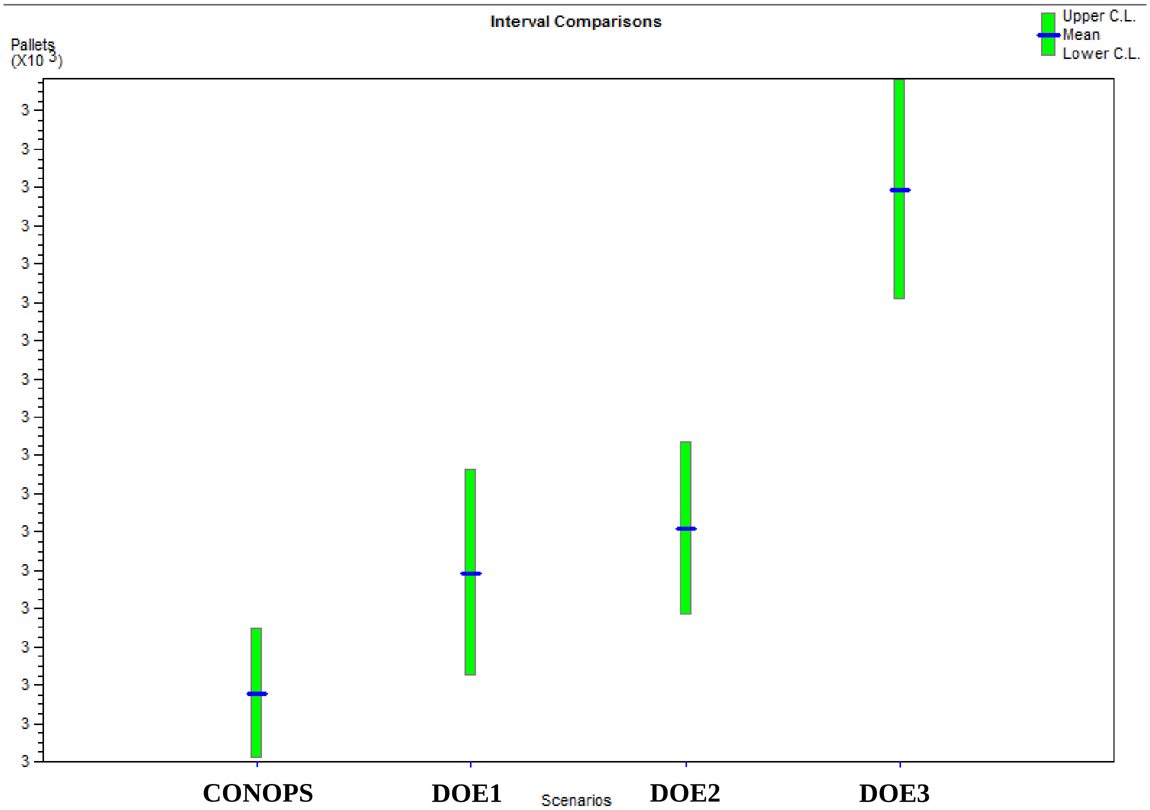


Figure 34: Confidence Interval Comparisons

In order for the results of an ANOVA to be considered reliable, the assumptions must be first examined (normality, constant variance and independence of the residuals). Figure 35 identifies that the residuals visually pass the test for normality. Figure 36 identifies that the residuals do not exhibit any heteroscedasticity in the residuals and thus visually exhibit equal constant variance. Since simulation has robust random number generation it safe to assume independent random observations. The assumptions for ANOVA pass thus the results to the investigative questions can be fulfilled next.

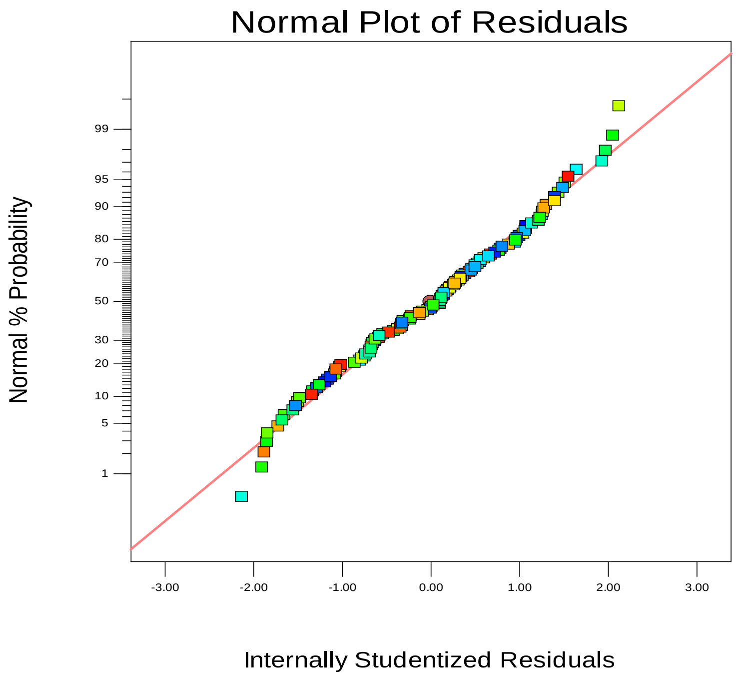


Figure 35: Assumption Test for Normality

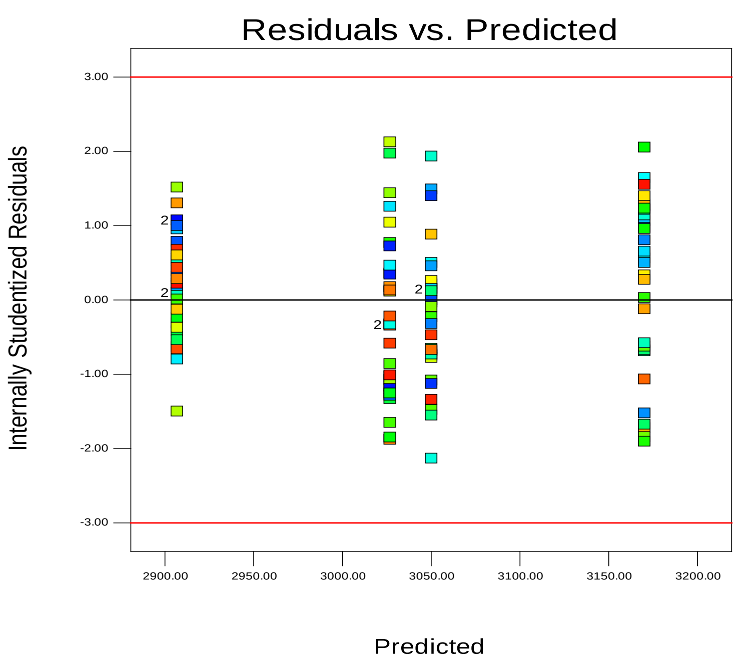


Figure 36: Assumption Test for Constant Variance

Results of the Investigative Questions

IQ1: What is the throughput of inbound cargo under planned concept of operations (CONOPS) given the conditions of an HA/DR environment?

Throughput of cargo under planned CONOPS given the conditions of an HA/DR environment resulted in 2,935 pallets.

IQ2: How does inbound cargo throughput respond to a change in the working maximum on ground (MOG) resources given the conditions of an HA/DR environment?

Throughput of inbound cargo under an increase in the working MOG resources given the conditions of an HA/DR environment resulted in 2,999 pallets if Working MOG is the sole increase in resources.

IQ3: How does inbound cargo throughput respond to a change in the distribution MOG resources given the conditions of an HA/DR environment?

Throughput of inbound cargo under an increase in the distribution yard capability given the conditions of an HA/DR environment resulted in 3,022 pallets if Distribution MOG is the sole increase in resources.

Answer to the Research Question

The purpose of this research was to create a decision model through discrete-event simulation to support JTF-PO operational planning in order to predict throughput of cargo under HA/DR scenario using aircraft and cargo data collected from Operation UNIFIED RESPONSE. The result of the research question is highlighted by Figure 37. The increase of the Working MOG increases pallet throughput by 2%. The increase of

Distribution MOG increases pallet throughput by 3%. The increase of both MOG resources increases pallet throughput by 8%. This suggests that an increase in Distribution MOG should be considered before an increase in Working MOG because it results in a 1% larger increase. But in order to maximize cargo throughput, an increase of both resources should be considered because they result in the largest percentage increase over all others.

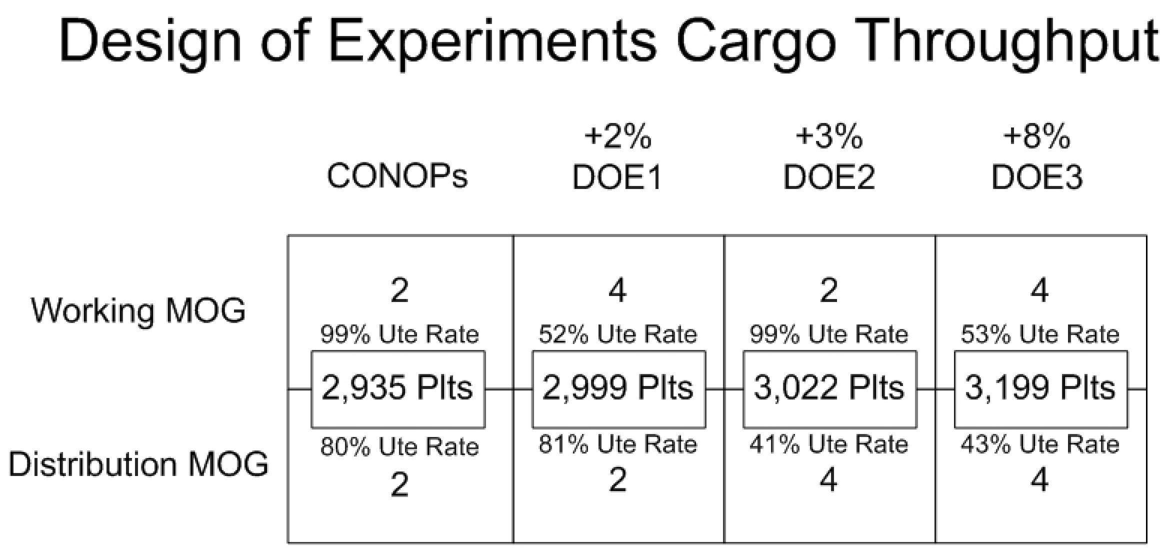


Figure 37: Design of Experiments Cargo Throughput Results

Conclusion

This chapter validated the JTF-PO simulation model by comparing its output measures against the output measures retrieved from Operation UNIFIED RESPONSE in order to compare the simulation model's resemblance of real world operations. The next section analyzed the experimental design and conducted statistical testing to determine differences between experiments. Finally, the chapter ended with results to answer the investigative questions and research question.

V. Conclusion and Remarks

Introduction

This chapter begins with a summary of the research conducted. Next, the research conclusion section reports its findings. The chapter concludes with recommendations for future research.

Research Summary

The simulation model developed for this research provides JTF-PO decision makers the ability to predict cargo throughput in a HA/DR scenario using aircraft and cargo data collected from Operation UNIFIED RESPONSE. Though not all operations are the same, the result of this study provides the decision makers a baseline to measure against other potential scenario outputs resulting from adjustments made to the simulation model.

Model Verification was accomplished through the use of two SMEs, the JTF-PO leadership and the Center for Operational Analysis Lab in the Department of Operational Science from the Air Force Institute of Technology. Furthermore, dynamic verification was conducted by running the model iteratively and comparing results with expected outcomes. The purpose of this step was to ensure the model was built *correctly*.

Model validation was accomplished using a three-step approach to ensure the *correct* model is constructed. The first step consisted of producing a model with high face validity and to ensure the correct use of the Arena® software. Furthermore, JTF-PO SMEs were used to ensure the correct processes were included in the model. The second step utilized Arena's Input Analyzer® software to validate the assumptions of the statistical distributions of the data. The third step compared the output of the simulation with the output reported from Operation UNIFIED RESPONSE for which the data was collected. The limitation of the model was constrained by the fidelity of the data collected and thus provided a close resemblance of real-world operations, but not a perfect match.

Research Conclusion

After the verification and validation, Design of Experiments was utilized to plan the statistical experimentation of four different scenarios resulting in a two factorial design. A baseline model was constructed under the planned JTF-PO Concept of Operations. Three more scenarios tested the effects of adjusting aerial port and distribution section resources on cargo throughput.

The experiments suggest that, under the research assumptions, an increase in both Working and Distribution MOG resources will result in the largest percentage increase in pallet throughput. If given the opportunity to increase resources in a JTF-PO operation in order to increase pallet throughput, Distribution MOG resources have small 1% advantage over Working MOG resources, but the largest impact should be to increase both resources.

Furthermore, this research indicates that utilization rates are extremely high for the Working MOG and Distribution MOG resources under the CONOPS scenario. By doubling the capacity of the Working MOG, the utilization rates are cut by 47% and doubling the capacity of the Distribution MOG, the utilization rates are reduced by 39%. If given the opportunity to increase resources in a JTF-PO operation in order to reduce utilization rates, Working MOG resources have an advantage over Distribution MOG resources and should be considered first. However, taken together with pallet throughput, an increase in both resources results in increased pallet throughput and decreased resource utilization rates. The result of less utilization in the resources would free them up and allow JTF-PO leadership the ability to employ them in areas that may require additional assistance. Increasing both Working and Distribution MOG resources should be the focus of decision makers when it comes to maximizing cargo throughput and reducing resource utilization.

Recommended Future Research

Any research has limitations and can be improved upon, this research is no exception. The data used was not obtained from ITV systems, but from manually inputted spreadsheets. This is due to the nature of the global response to the operation and lack of integrated ITV systems with the international aviation community. If ITV systems become integrated internationally, better use of them will produce better data which will resort in more robust simulations of humanitarian operations.

Measures of Interest

This model considered cargo throughput as the output of interest. By including aircraft arrival distributions that mimic other real-world operations, a study of the difference in aircraft throughput could be measured and compared with the baseline model of this study. By doing so, the effects of adjusting the working MOG resources could measure aircraft throughput.

Another measure of interest that was not included in the model would be fuel usage. A collection of fuel usage of JTF-PO resources in the model (Aerial_Port_Teams, Clearance_Section_Teams, HEMTT_LHS, and Distribution_Section_Teams) would determine fuel demand of their respective material handling equipment (MHE). This would provide decision makers the ability to calculate the fuel requirements of MHE.

Furthermore, including a customer arrival distribution at the end of the simulation will allow the model to measure the effectiveness of the forward node operations under different customer arrival criteria. This would allow decision makers the ability to study the queue of cargo at the forward node based on a customer arrival distribution.

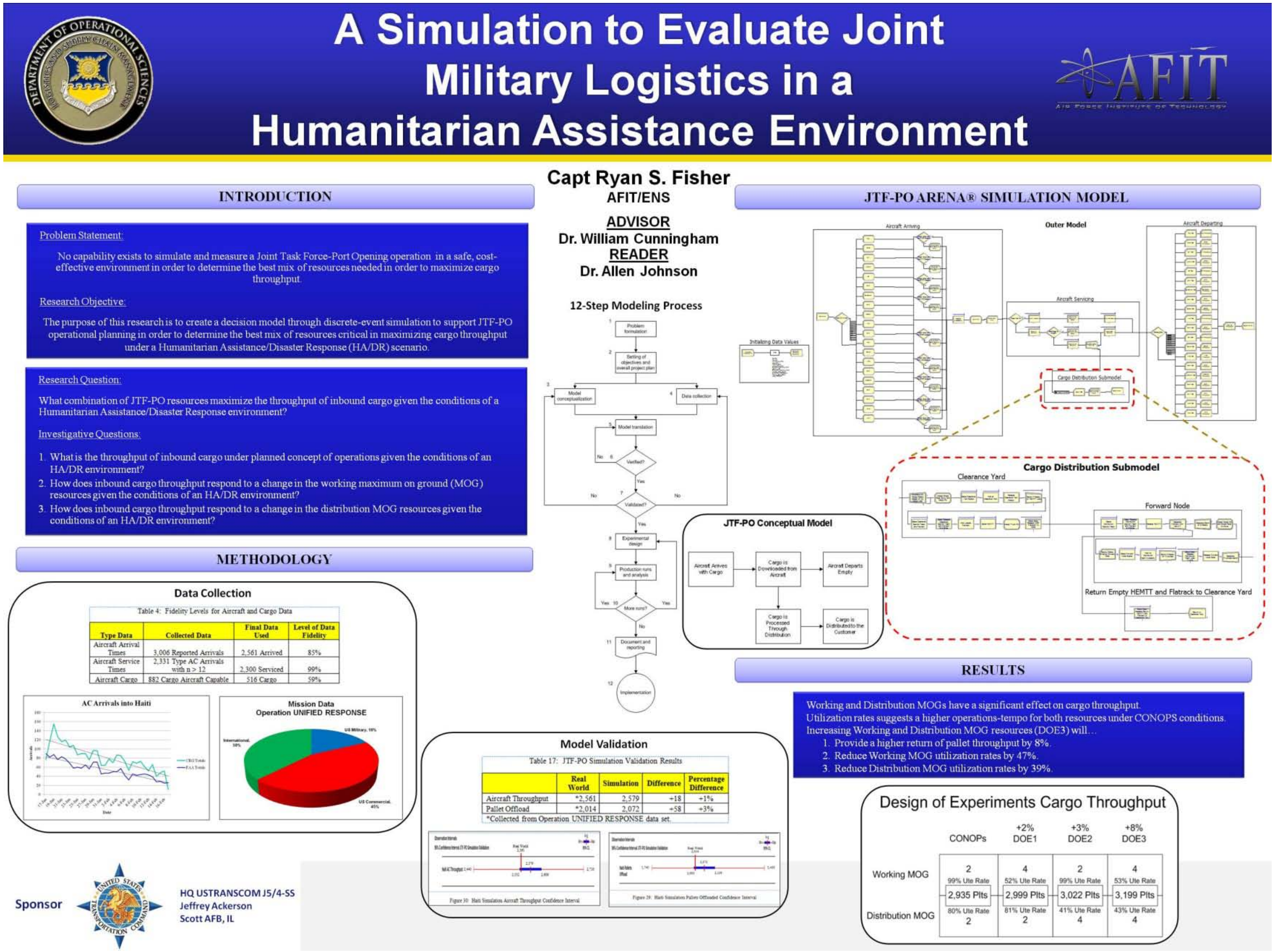
Since the JTF-PO mission is required to fulfill passenger processing, another measure of interest to be included into the model is the processing of outbound passengers. A study of the resources needed and associated times of service along with a distribution of passenger arrivals into a process queue would be required. This would provide decision makers the ability to add to the aerial port resources for passenger processing mission and provide a third measured output of interest, passenger throughput.

This thesis focused on only two resources of interest, Aerial_Port_Team and Distribution_Section_Team. This simulation has the potential to adjust the other 12 resources included in the model in order to study the throughput of cargo and their utilization rates. By doing so, decision makers will have the ability to consider bottlenecks in the process and address them appropriately.

Conclusion

This chapter began with a summary of the research conducted. Next, the research conclusion section reported its findings. The chapter concluded with recommendations for future research. The results of this research suggest the JTF-PO simulation model can be used as a baseline model and modified for future studies. It is a good starting point that can only be improved upon as increased fidelity of data sources become available that would reduce the limitations imposed upon it.

Appendix A


A Simulation to Evaluate Joint Military Logistics in a Humanitarian Assistance Environment
AFIT
Capt Ryan S. Fisher
AFIT/ENS
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INTRODUCTION
Problem Statement:
No capability exists to simulate and measure a Joint Task Force-Port Opening operation in a safe, cost-effective environment in order to determine the best mix of resources needed in order to maximize cargo throughput.
Research Objective:
The purpose of this research is to create a decision model through discrete-event simulation to support JTF-PO operational planning in order to determine the best mix of resources critical in maximizing cargo throughput under a Humanitarian Assistance/Disaster Response (HA/DR) scenario.
Research Question:
What combination of JTF-PO resources maximize the throughput of inbound cargo given the conditions of a Humanitarian Assistance/Disaster Response environment?
Investigative Questions:
1. What is the throughput of inbound cargo under planned concept of operations given the conditions of an HA/DR environment?
2. How does inbound cargo throughput respond to a change in the working maximum on ground (MOG) resources given the conditions of an HA/DR environment?
3. How does inbound cargo throughput respond to a change in the distribution MOG resources given the conditions of an HA/DR environment?
METHODOLOGY
Data Collection
Table 4: Fidelity Levels for Aircraft and Cargo Data
Type Data | Collected Data | Final Data Used | Level of Data Fidelity
Aircraft Arrival Times | 3,006 Reported Arrivals | 2,561 Arrived | 85%
Aircraft Service Times | 2,331 Type AC Arrivals with n > 12 | 2,300 Serviced | 99%
Aircraft Cargo | 882 Cargo Aircraft Capable | 516 Cargo | 59%
AC Arrivals into Haiti
Mission Data
Operation UNIFIED RESPONSE
12-Step Modeling Process
Problem formulation
Setting of objectives and overall project plan
Model conceptualization
Data collection
Model translation
Verified?
Validated?
Experimental design
Production runs and analysis
More runs?
Document and reporting
Implementation
JTF-PO Conceptual Model
Aircraft Arrives with Cargo
Cargo is Downloaded from Aircraft
Aircraft Departs Empty
Cargo is Processed Through Distribution
Cargo is Distributed to the Customer
Model Validation
Table 17: JTF-PO Simulation Validation Results
 | Real World | Simulation | Difference | Percentage Difference
Aircraft Throughput | *2,561 | 2,579 | +18 | +1%
Pallet Offload | *2,014 | 2,072 | +58 | +3%
*Collected from Operation UNIFIED RESPONSE data set.
JTF-PO ARENA® SIMULATION MODEL
Outer Model
Aircraft Arriving
Aircraft Servicing
Aircraft Departing
Initializing Data Values
Cargo Distribution Submodel
Clearance Yard
Forward Node
Return Empty HEMTT and Flatrack to Clearance Yard
RESULTS
Working and Distribution MOGs have a significant effect on cargo throughput.
Utilization rates suggests a higher operations-tempo for both resources under CONOPS conditions.
Increasing Working and Distribution MOG resources (DOE3) will…
1. Provide a higher return of pallet throughput by 8%.
2. Reduce Working MOG utilization rates by 47%.
3. Reduce Distribution MOG utilization rates by 39%.
Design of Experiments Cargo Throughput
CONOPs | +2% DOE1 | +3% DOE2 | +8% DOE3
Working MOG | 2 | 4 | 2 | 4
99% Ute Rate | 52% Ute Rate | 99% Ute Rate | 53% Ute Rate
2,935 Plts | 2,999 Plts | 3,022 Plts | 3,199 Plts
Distribution MOG | 80% Ute Rate | 81% Ute Rate | 41% Ute Rate | 43% Ute Rate
2 | 2 | 4 | 4
Sponsor
HQ USTRANSCOM J5/4-SS
Jeffrey Ackerson
Scott AFB, IL

Appendix B

JOURNAL ARTICLE MANUSCRIPT

A SIMULATION TO EVALUATE JOINT MILITARY LOGISTICS IN A HUMANITARIAN ASSISTANCE OPERATION

Introduction

Background

Expeditionary Air Force units designed to open airfields are not new to the military, but a rapidly deployable multi-modal and distribution concept is a young capability. Since World War II, the Air Force has slowly transitioned from massive war-fighting capability stationed all around the world to a light, lean, and lethal expeditionary capability designed to deploy to anywhere in the world.

During an overarching Air Force service restructure in 1997, numerous functions required to operate forward mobility locations were realigned under one command, Air Mobility Command. The Air Mobility Operations Group (AMOG) was formed to establish key capabilities needed to rapidly open and operate an airfield under deployed conditions for short periods of time. (Zahn, 2007) In 1999, the transition from AMOG to a new concept called the Contingency Response Group (CRG) was initiated by General John P. Jumper, Commander United States Air Forces in Europe (USAFE). Though the AMOG was a useful tool in air mobility operations, the benefit of the CRG lies in its cross-functionality of 40 Air Force capabilities under a single commander. (Jumper, 1999)

In 2005, the Defense Science Board Task Force on Mobility identified the need for improvements in expeditionary rapid port opening, throughput capabilities, movement synchronization and increased asset visibility. After action reports from contingency operations such as Operations ALLIED FORCE, ENDURING FREEDOM, and IRAQI FREEDOM highlighted the challenges of integrating port and distribution operations. In response to the board, United States Transportation Command (USTRANSCOM) built upon the capability of the Air Force port centric CRG and created the Joint Task Force-Port Opening (JTF-PO). The creation of the Army distribution centric Rapid Port Opening Element (RPOE) resulted in culmination of the JTF-PO concept and reached initial operation capable (IOC) on 2 November 2006. JTF-PO provides the capability to rapidly deploy contingency response Air Force and Army personnel for initial theater Aerial Port of Debarkation (APOD) deployment and distribution operations within 12 hours notice. (United States Transportation Command, 2009) To maintain superiority in this capability, joint force personnel and equipment must maintain an alert status 365 days a year. USTRANSCOM defines the mission of a JTF-PO in its Concept of Operations (CONOPs) below:

> "Provide a joint expeditionary capability to rapidly establish and initially operate a port of debarkation and distribution node, facilitating port throughput in support of combatant commander executed contingencies."

Currently, USTRANSCOM develops and coordinates joint exercises in order to provide training opportunities for JTF-PO personnel and CCDR operational staffs. The training events also provide the opportunity to identify, test and validate procedures and processes for opening distribution networks. (United States Transportation Command, 2009) Though it is necessary to train for experience, it is a costly way to do it solely to identify, test and validate new concepts.

Problem Statement

Currently, no capability exists to simulate and measure a Joint Task Force-Port Opening operation in a safe, cost-effective environment in order to determine the best mix of resources needed in order to maximize cargo throughput. The benefits of a good planning tool will allow USTRANSCOM the ability to better estimate resources needed and identify potential bottlenecks through the use of Arena® Simulation software. The logical progression of this research evaluates the factors currently used in the JTF-PO process as well as experimenting with the changes in resource capacities.

Research Objective

The purpose of this research is to create a decision model through discrete-event simulation to support JTF-PO operational planning in order to determine the best mix of resources critical in maximizing cargo throughput under a Humanitarian Assistance/Disaster Response (HA/DR) environment. Aircraft and cargo data collected from Operation UNIFIED RESPONSE will be used to input into the model. In order to provide USTRANSCOM a preferred decision model, the following research question (RQ) is addressed:

RQ: What combination of JTF-PO resources maximize the throughput of inbound cargo given the conditions of an HA/DR environment?

In order to answer the research question, the following investigative questions (IQs) are addressed.

IQ1: What is the throughput of inbound cargo under planned concept of operations given the conditions of an HA/DR environment?

IQ2: How does inbound cargo throughput respond to a change in the working maximum on ground (MOG) resources given the conditions of an HA/DR environment?

IQ3: How does inbound cargo throughput respond to a change in the distribution MOG resources given the conditions of an HA/DR environment?

Operation UNIFIED RESPONSE

On 12 January 2010, a 7.0 magnitude earthquake rocked Port-au-Prince, Haiti leaving the city demolished and thousands of people desperate for international aid. Transportation infrastructure was demolished on all accounts to include the main seaport and border crossing routes. The Toussaint L'Ouverture International Airport sustained damage to its facility, but the airfield was still usable. It was clear the fastest way to get relief into the hands of Haitian people was to move in by air. Initial Air Force capabilities entered 24 hours after the earthquake from the 1st Special Operations Wing (SOW) from Hurlburt Field, Florida. The unit brought with them the capability to control air traffic arrivals into the heavily congested single runway and single taxiway airport. (JTF-PO/CC, 2010)

Figure 38: Toussaint Louverture International Airport (Google Earth)

On 14 January 2010, USTRANSCOM tasked an Air Force CRG and Army RPOE unit for the first time to form the JTF-PO capability. The mission was to establish command and control, aerial port operations, quick-turn aircraft maintenance, and a distribution network in order to maximize humanitarian assistance throughput. (JTF-PO/CC, 2010)

The JTF-PO established operations at the east end of the ramp and consisted of the JTF-PO camp, cargo yard, road, and forward cargo node. The JTF-PO camp was the home of leadership facilities used to conduct command and control of airfield and distribution network operations. The cargo yard was the entrance of cargo into the distribution network and consisted of both Air Force and Army personnel tasked to sort and determine which items move to the forward cargo node. The road, also known as the

Main Supply Route (MSR), was used to transport cargo between the cargo yard and forward cargo node. The forward cargo node was the location tasked to distribute the cargo to its owners. (Fisher, 2011)

Figure 39: JTF-PO Operations, Operation UNIFIED RESPONSE (JTF-PO/CC, 2010)

Maximum on Ground (MOG) is used to describe the maximum number of aircraft on the ground and is broken down into parking MOG and working MOG. Parking MOG refers to the maximum number of aircraft that can be parked at one time on an airfield. Working MOG identifies the maximum number of aircraft that can be worked (parked and serviced) at one time. (JTF-PO/CC, 2010) The more restrictive of the two measures generally equates to the limiting factor of MOG. (Anon., 13 January 2008)

The parking ramp in Haiti consisted of ten C-17 equivalent parking spaces and was managed by aircraft maintenance. The thirteen-man maintenance package planned to work a parking MOG capability of two but was expected to work four at one time. The best way to meet the expectations was to split each shift of maintainers in half, allowing one team to work half the ramp and the other team to work the other half. (Wallwork, et al., 2010) Furthermore, the aerial port teams utilized the same tactics and split shifts in order to download aircraft more efficiently. The decision for both capabilities allowed faster turn-around time of aircraft through the airfield. (Fisher, 2011)

Figure 40: Parking Ramp, Operation UNIFIED RESPONSE (JTF-PO/CC, 2010)

Though maximizing humanitarian assistance throughput was the mission of the JTF-PO, so was returning operations back to the GoH. Prior to the departure of the JTF-PO, the GoH resumed commercial operations on 19 February with the first American Airlines flight arriving on 19 February 2010. (Air Forces Southern, Public Affairs, 2010) In 37 days, the JTF-PO was able to amass working 3,006 relief missions, download over 30.9 million pounds of cargo and evacuate 15,495 American Citizens (AMCITs). (JTF-PO/CC, 2010)

Table 21: Mission Data for Operation UNIFIED RESPONSE
14 Jan – 19 Feb 2010 (JTF-PO/CC, 2010)

MISSION DATA Operation UNIFIED RESPONSE	
C-17 Missions/Sorties	253/506
C-130 Missions/Sorties	283/566
US Commercial Missions/Sorties	1339/2678
International Missions/Sorties	1131/2262
TOTAL Missions/Sorties	3006/6012
Air Evacuation Missions:	301 Litter, 10 Ambulatory
Off-Load Passengers:	9,509
Off-Load Cargo:	15,450 ST
On-Load Passengers:	15,495
On-Load Cargo:	253 ST

Design/Method/Approach

Simulation

Simulation is the process of designing and creating a computerized model of a real or proposed system for the purpose of conducting numerical experiments to give a better understanding of the behavior of that system for a given set of conditions. (Kelton, et al., 2007) The type of modeling approach used for this research is a logical-computer simulation. The logical-computer simulation has the ability to address questions about the model's behavior under faster, safer, and cost-efficient conditions by simply manipulating the program's inputs and logic. (Kelton, et al., 2007) Furthermore, Kelton and others (2007) explain that computer simulation allows the researcher to duplicate and study complex systems that may not have exact mathematical solutions worked out. Complex systems frequently simulated are airport flight arrivals and distribution networks.

Discrete-Event Simulation

Discrete-event simulation is the modeling of systems in which the state variable changes only at a discrete set of points in time. (Banks, et al., 2010) Due to the nature of this research, the approach of discrete-event simulation is employed through the aid of computers in order to "run" rather than "solve" numerical models. The choice of software for modeling is the Rockwell Corporation's Arena® simulation software due to the ability to capture the dynamic nature of the JTF-PO mission. The software generates an artificial history of the system built from model assumptions and observations of each "run" result is collected to be analyzed and to estimate system performance measures. (Banks, et al., 2010) Though simulation can solve simple mathematical problems, the best use of its capability is performed on complex systems. The JTF-PO and related distribution systems is a perfect match for utilizing simulation because of the complex nature of entity arrivals, service times, and network flow.

Model Development

Banks and others (2010) identify a 12-step process in Figure 4 for developing a simulation model which applies to any model building effort; it provides the structure for this research. In Stieglemeiere's research (2006), he breaks-down the description of the process into two halves. The first half, (Steps 1-7), represent the effort undertaken to build, validate, and verify the model. The second half, (Steps 8-12), represent the actual use of a model to analyze a system and make decisions about it. The 12-step process is approach of choice to develop the simulation model.

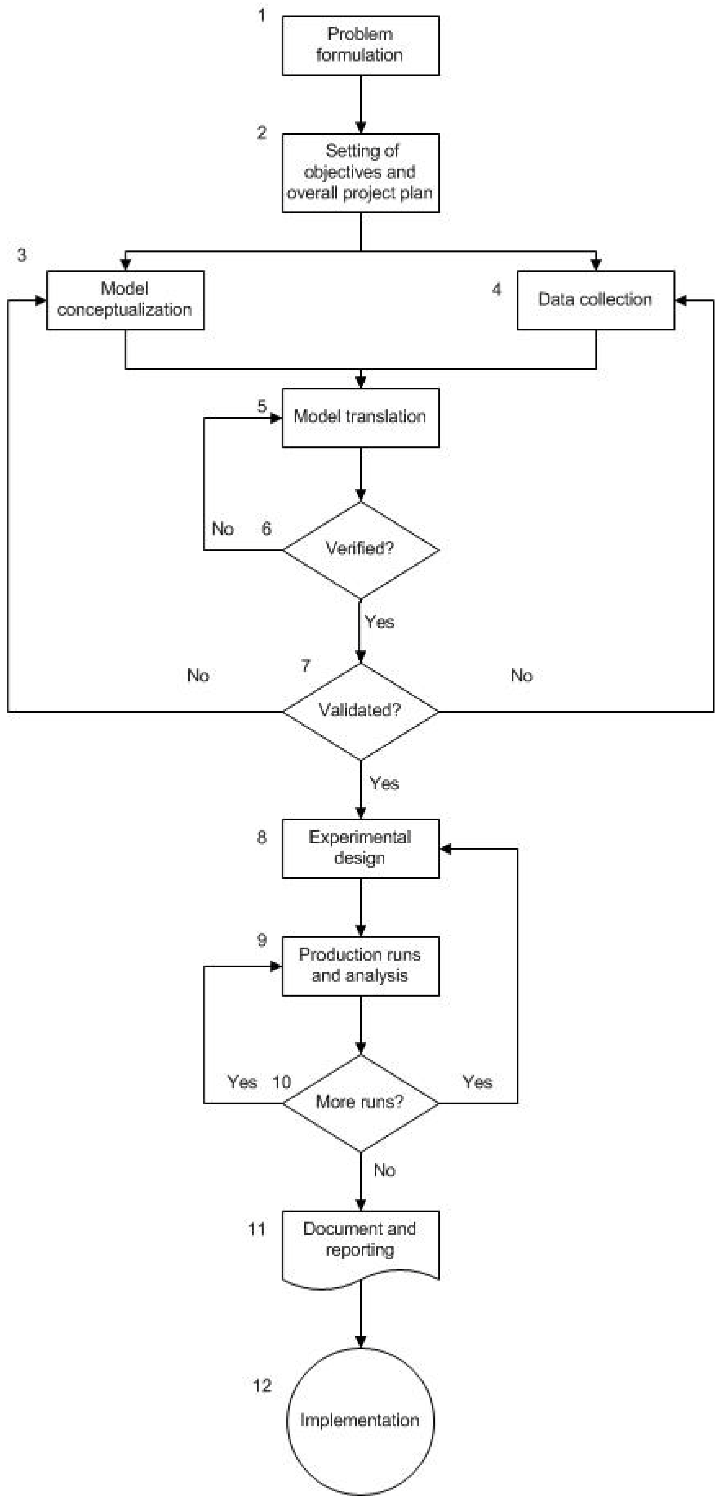

Figure 41: Steps in a Simulation Study (Banks, et al., 2010)

The 12-Step Modeling Process

Step 1: Problem Formulation

The first step to solving any problem in a study is to formulate a statement of the problem. (Banks, et al., 2010) USTRANSCOM clearly defined the problem that there is currently no capability to model a JTF-PO operation in a safe, cost-effective environment in order to predict throughput of cargo based on the availability of resources.

Step 2: Setting of Objectives and Overall Plan

The objectives indicate the questions to be answered by simulation. (Banks, et al., 2010) The purpose of this research is to create a decision model through discrete-event simulation to support JTF-PO operational planning in order to predict throughput of cargo under a HA/DR scenario.

Step 3: Model Conceptualization

This step is one of the lengthiest in the modeling process in that model construction is more an art than a science. The art of modeling is enhanced by an ability to abstract the essential features of a problem, to select and modify basic assumptions that characterize the system, and then to enrich and elaborate the model until a useful approximation results. (Banks, et al., 2010) Simulation modeling is an iterative process that requires a modeler to start with a simple model and develops it to mirror the real-world workings of the system. The model for this research was logically built from the experience of subject matter experts, and was constrained by the available data. Furthermore, involvement of subject matter experts contributed to enhance the quality of the resulting model and increase the confidence of its application. Figure 5 identifies the conceptual model in its simplest form.

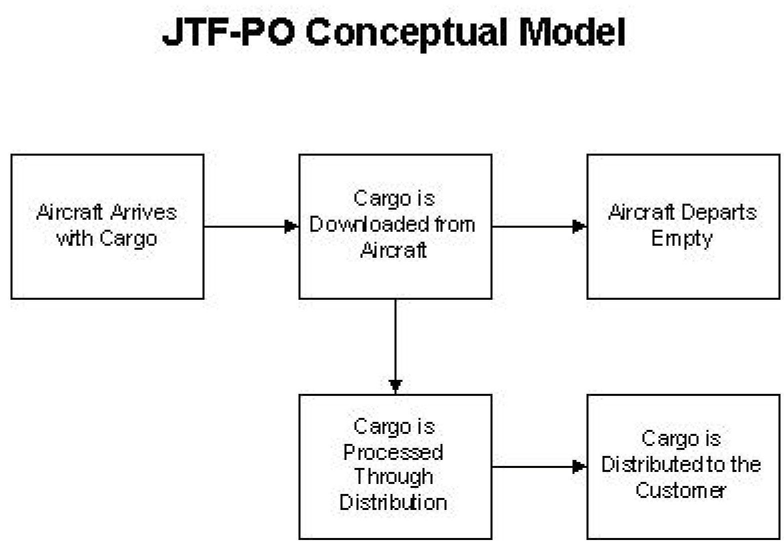

Figure 42: JTF-PO Conceptual Model

Step 4: Data Collection

Historical data collection is performed during this step and is utilized in conjunction with the conceptual model building. Normally, the objectives of this study dictate the kind of data to be collected; this research utilized a reverse approach. Data was collected prior to model conceptualization. This provided limitations in the model building. The data was collected from two separate subject matter expert (SME) sources Command and Control (C2) leadership and Air Terminal Operations Center (ATOC) personnel from Operation UNIFIED RESPONSE and are categorized below with varying levels of fidelity.

Table 22: Fidelity Levels for Aircraft and Cargo Data

Type Data	Collected Data	Final Data Used	Level of Data Fidelity
Aircraft Arrival Times	3,006 Reported Arrivals	2,561 Arrived	85%
Aircraft Service Times	2,331 Type AC Arrivals with n > 12	2,300 Serviced	99%
Aircraft Cargo	882 Cargo Aircraft Capable	516 Cargo	59%

In order to show validation in the data collected from the C2 personnel, daily aggregated aircraft arrivals were obtained from the Federal Aviation Administration's Enhanced Traffic Management System Counts (FAA ETMSC) and were compared with the CRG totals. Both of the collected totals follow the same negative trend, as can be seen by Figure 6, with a residual difference mean of 28 arrivals and standard deviation of 12 arrivals. The reason for the difference in arrivals is due to the CRGs ability to collect unscheduled aircraft arrivals from day one. Though the FAA set up a slot-management system to schedule all arrivals a few days after the earthquake, unscheduled aircraft were still arriving to the location. Therefore on-scene data collection represents the most accurate arrival data. (Jones, 2011)

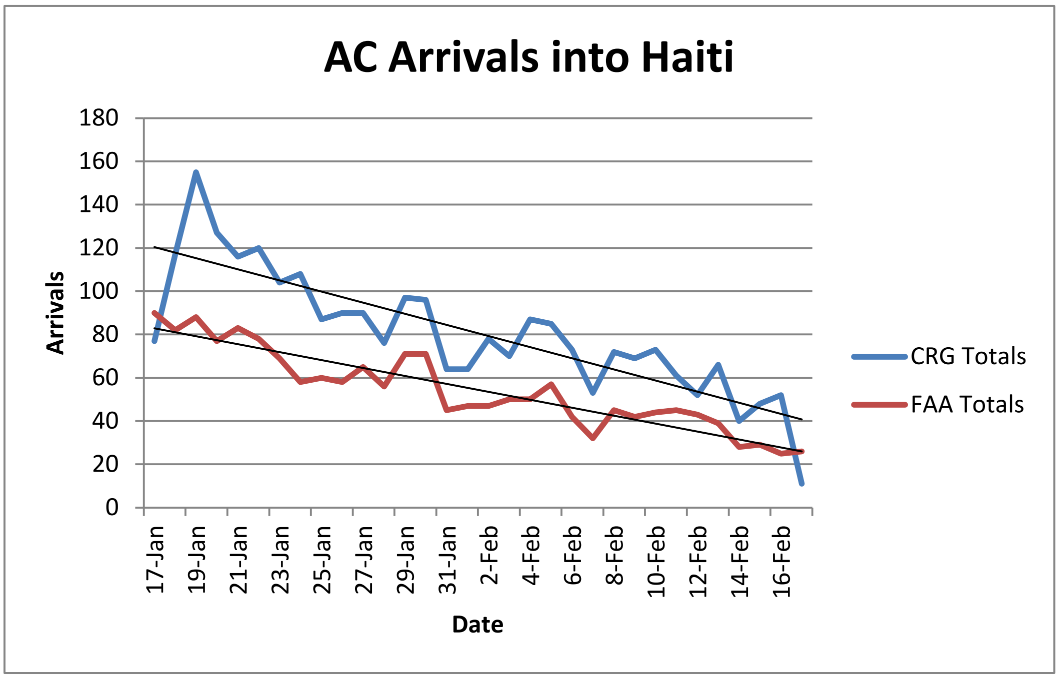

Figure 43: Daily Aircraft Arrivals into Haiti

There were two significant challenges faced for collecting and reporting cargo statistics. These were due to the fact that 82% of aircraft arrived via US commercial or international carriers. First, the majority of aircraft arrivals were not tracked with radio frequency identification (RFID) tags because there is no integrated RFID network that is shared between the international communities. This challenge forced personnel to manually track cargo from arrival into the airport through departure to the customer. (Fisher, 2011) Second, the cargo, loaded onto the 82% majority of arrivals, did not exhibit the characteristics of the traditional United States military 463L pallet configuration (88" x 108"). This presented the problem of determining the unit of measure to use when counting the download and distribution of cargo. For cargo that arrived in warehouse skid configuration, a simple mathematical conversion was used to transform four skids into one 463L pallet equivalent. (JTF-PO/CC, 2010) Larger commercial pallets (88" x 125") were considered the same pallet type as the 463L and no conversion was utilized. (Kuppinger, 2011)

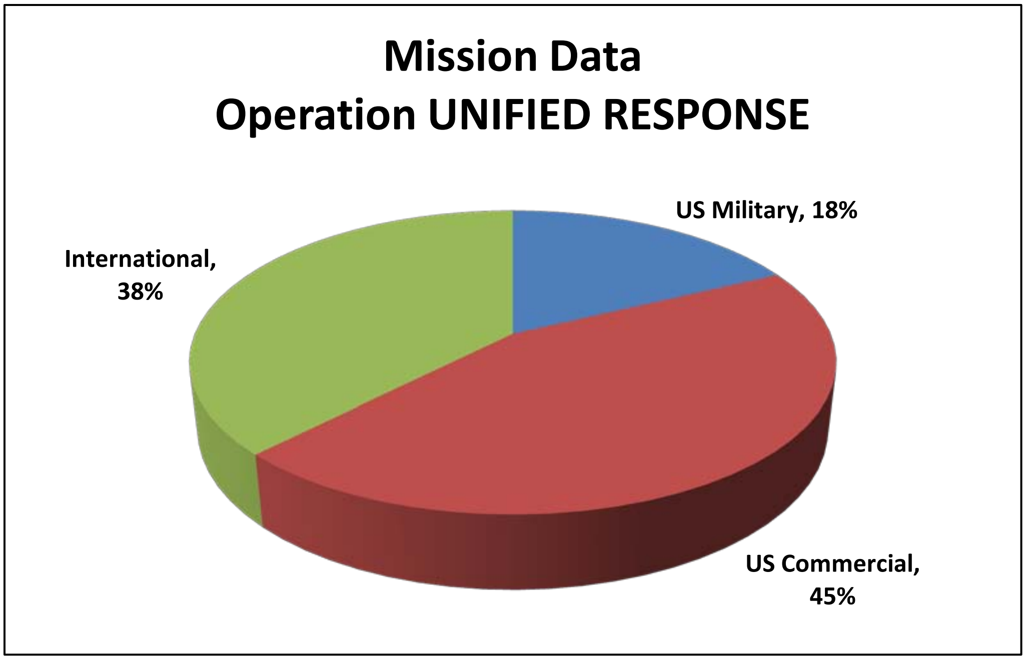

Figure 44: Airlift Carriers

Step 5: Model Translation

This step translates the conceptual model into either simulation language or special-purpose simulation software. Utilizing the Arena® software greatly reduces the time to develop the model and is flexible enough to handle dynamic defense logistic networks. The final simulation consists of two parts, an outer model and cargo distribution submodel which can be seen in Figure 8 and Figure 9.

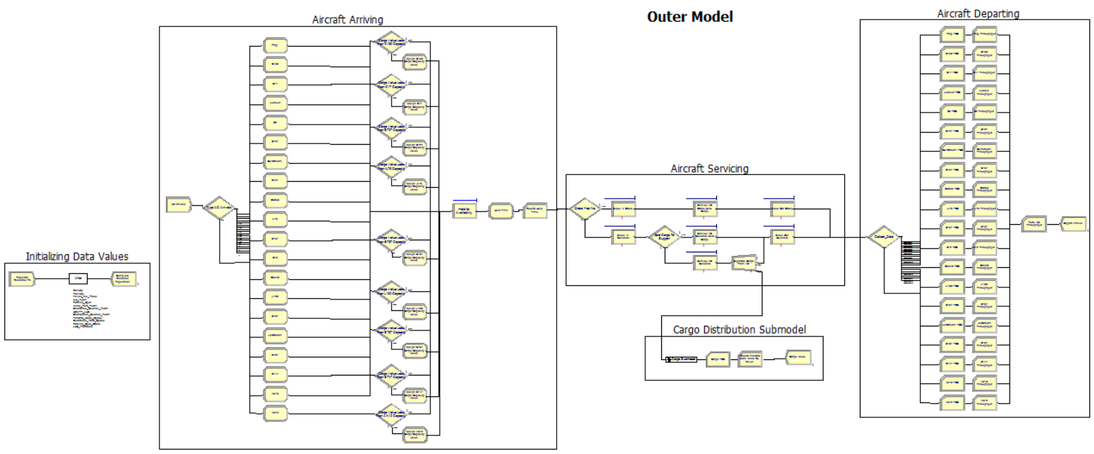

Figure 45: Outer Model

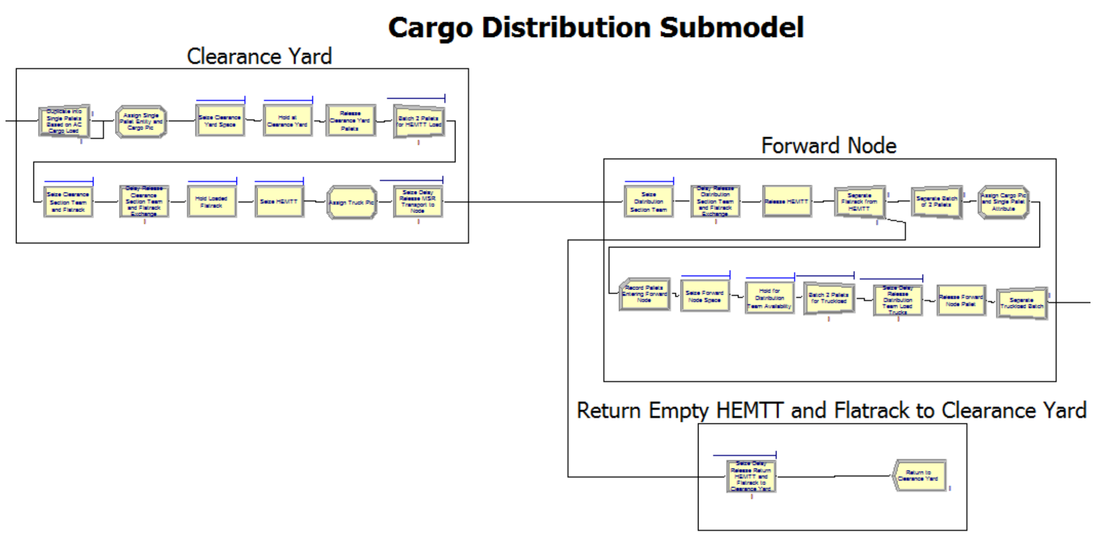

Figure 46: Cargo Distribution Submodel

Step 6: Verification

"Model verification is substantiating that the model is transformed from one form into another, as intended, with sufficient accuracy." (Balci, 1997) In essence, verification is building the model *correctly*. Domain and simulation SMEs are used in this research to verify the correctness of the model building. (Defense Modeling and

Simulation Office, 2000) The domain SME has knowledge of the studied network flow and is needed to create a description of the conceptual model. JTF-PO SMEs are used to verify the accuracy of the JTF-PO model concept. The simulation SME has knowledge of the required simulation software to enable the developer to employ appropriate tools and techniques to accurately develop the conceptual model into a computer simulation model. The support staff for Center for Operational Analysis Lab in the Department of Operational Sciences at the Air Force Institute of Technology is used to verify the accuracy of the transformation of the model from concept to computer simulation.

In a study conducted by Stieglemeier (2006) a dynamic verification technique was used to test the decision nodes in a simulation model. The Defense Modeling and Simulation Office defined dynamic verification as a test carried out by running a model then observing its behavior. The same dynamic verification approach is utilized to assess the logical flow of entities designed to enter decision nodes that separate, duplicate, or decide a certain path. This study is concerned with the throughput of entities, thus record modules were placed immediately after each decision node to test the expected outcome against the actual outcome. Banks and others (2010), support this concept by identifying that total count statistics can give an indication of the reasonableness of the model Total count refers to the total number of items that have entered each component.

Step 7: Validation

"Model validation is substantiating that the model, within its domain of applicability, behaves with satisfactory accuracy consistent with the modeling and simulation objectives." (Balci, 1997) In essence, validation is building the *correct* model. Banks and others (2010) discussed a three-step approach for validating a model from Naylor and Finger (1967). This research utilized the approach for validating the simulation.

<u>Step 1. Build a model that has high face validity:</u>

Face validity refers to a model that appears reasonable on its face to model users and others who are knowledgeable about the real system being simulated. (Banks, et al., 2010) Through the use of SMEs and the model user, output measures are evaluated to identify model deficiencies. Furthermore, by involving the user, the perception of credibility and validity is increased which allows them to trust the use of the simulation for future decision making.

<u>Step 2. Validate model assumptions:</u>

Model assumptions fall into two categories, structural assumptions and data assumptions and were verified by SMEs from Operation UNIFIED RESPONSE. Structural assumptions involve questions of how the system operates under simplifications from reality. (Banks, et al., 2010) Data assumptions should be based on the collection of reliable data and correct statistical analysis of the data. (Banks, et al., 2010) Procedures for analyzing input data were completed through the use of Arena's

Input Analyzer® software. Identifying the appropriate stochastic distribution, parameters and goodness-of-fit tests (through the use of Kolmogorov-Smirnoff (KS) and Chi Square (ChiSq) tests) were the results of the software. The best distributions were selected based on the p-values > .05 and or the visual histogram fit.

Step 3. Compare input/output transformations with historical data:

The third and final step in the validation will result in comparing the output data from the simulation with the collected data sets. The model validation consists of simulating Operation UNIFIED RESPONSE in order to measure its offload of cargo and throughput of aircraft in the system. Using the validated stochastic distributions identified in step 2, the resources identified in Table 3, the operation was simulated under 30 replications for 32 days. The simulation results are compared to the results of reality to determine if the model is a valid representation of the real world.

Table 23: Haiti Resource Quantities

Resource	Qty
Runway	1
Taxiway	1
Follow_Me_Truck	1
MX_Team	2
Parking_Spot	10
Parking_Spot_Grass	4
Aerial_Port_Team	2 - 5*
Clearance_Yard_Space	276
Clearance_Section_Team	2
HEMTT_LHS	4
LHS_Flatracks	24
MSR	Infinite
Forward_Node_Space	450
Distribution_Section_Team	2

*Note: Aerial_Port_Team capacity started at 2 then increased to 5 on 21 January 2010 per AAR.

The results of the model validation are identified in Table 4. The real world column identifies the number of aircraft arrivals and cargo offload collected for 32 days (17 Jan – 17 Feb 2010). The simulation column identifies aircraft arrivals and cargo offload from 30 replications of 32 days. A difference of 18 arrivals indicates the simulation is collecting 1% above the documented aircraft arrivals in the operation. A difference of 58 pallets indicates the simulation is capturing 3% above the reported cargo offloaded.

Table 24: JTF-PO Simulation Validation Results

	Real World	**Simulation**	**Difference**	**Percentage Difference**
Aircraft Throughput	*2,561	2,579	+18	+1%
Pallet Offload	*2,014	2,072	+58	+3%

*Collected from Operation UNIFIED RESPONSE data set.

A 95% confidence interval was calculated around the simulation output to determine if the real world totals were captured within the lower and upper bounds of the its limits (Table 5, Figure 10 and Figure 11). The results indicate that the Real World Aircraft Throughput and Pallet Offload do fall within the limits of the simulated results. This indicates that the model makes valid representation of the real world data provided by the SMEs. The next step will be to conduct further experimental testing to determine the best-case scenario for future JTF-PO missions by adjusting the Working and Distribution MOG resources.

Table 25: Haiti Simulation 95% Confidence Interval Statistics

	Average	**Std Dev**	**Lower Confidence Limit**	**Upper Confidence Limit**	**Min**	**Max**
Aircraft Throughput	2,579	74	2,552	2,609	2,440	2,710
Pallet Offload	2,072	180	2,005	2,139	1,740	2,450

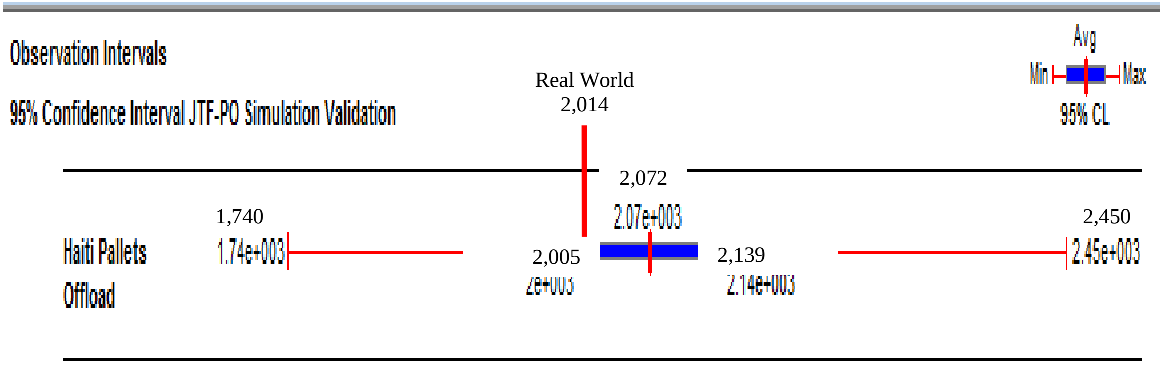

Figure 47: Haiti Simulation Pallets Offloaded Confidence Interval

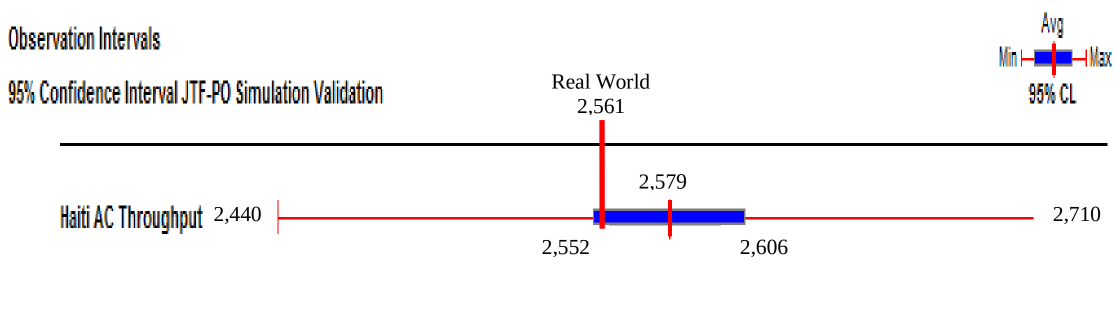

Figure 48: Haiti Simulation Aircraft Throughput Confidence Interval

Step 8: Experimental Design

In this step, alternatives to the model that are to be simulated must be determined for experimentation. (Banks, et al., 2010) This study uses Design of Experiments (DOE) to plan the statistical experimentation in an efficient scientific approach. DOE refers to the process of planning the experiment so that appropriate data will be collected and analyzed by statistical methods, resulting in valid and objective conclusions.

Factorial designs are widely used to experiment the response of several factors in a study. (Montgomery, 2009) The aim of this study is to report four responses based on the four treatments of two factors. This results in a 2^{-}factorial design. The objective of the experiment is to determine how adjustments to either of the two factors would affect the response. (Montgomery, 2009) In order to obtain enough point estimate values to support the central limit theorem ($n \geq 30$), 30 simulated replications are completed.

In order to reduce variance in the point estimators, Common Random Number (CRN) streams are used for each statistical distribution. CRN means that, for each replication, the same stream of random numbers is used to simulate each system. The purpose of using CRN is to introduce a positive correlation between the point estimates of each replication. This achieves a variance reduction in the mean difference between the point estimators. (Banks, et al., 2010) More detail in the experimental design is discussed in the next section.

Step 9: Production Runs and Analysis

This step is the execution of the simulation model and analysis of its output. (Banks, et al., 2010) More detail in the analysis and design is discussed in the next section.

Step 10: More Runs?

Given the analysis of runs completed for this research, more runs will be determined by the user of the model. The user will determine additional developments of experimental designs and execute them as appropriate.

Step 11: Documentation and Reporting

This research serves as the documentation and reporting of the development of this simulation model.

Step 12: Implementation

The objective of this simulation model is for it to be used for future decision making in JTF-PO operations conducting HA/DR missions. Upon completion of this research, the model was delivered to the user for implementation.

Assumptions/Limitations

The model created for this research is built upon assumptions derived from Department of Defense Regulations, JTF-PO subject matter experts (SMEs) and the data collected from the Operation UNIFIED RESPONSE after action report (AAR) in Port-au-Prince, Haiti 16 January – 17 February 2010.

Assumptions

1. Operation UNIFIED RESPONSE aircraft arrivals rates and times are representative of future scenarios.
2. 90% of all cargo is palletized at 10,000 pounds each.
3. All palletized cargo is loaded on the standard military 463L pallet.

4. Missing aircraft cargo data is treated as an empty aircraft.
5. No known delays in aircraft ground handling, or cargo distribution were annotated and are assumed out of the model.
6. Service times for aircraft are calculated as the difference between the arrival and departure of all aircraft.
7. Individual actions within the timeframe of aircraft servicing were not captured and therefore assumed to be factored into the service times. They are as follows, aerial port teams' transportation to aircraft, amount of time to download cargo, transport of cargo from aircraft to clearance yard, and any required upload of passengers or cargo.
8. All cargo is destined to the final staging point at the Forward Node.
9. Transport time of taxiing aircraft is held at a constant five minutes.
10. The main supply route is 10 kilometers long.
11. Truck speed on the main supply route is 15 kilometers per hour.
12. Transport time on the main supply route is 40 minutes one way between clearance yard and forward node.
13. Trucks are available at all times to receive cargo at the distribution point.
14. Trucks used by the customers have the same characteristics as the Heavy Expanded Mobility Tactical Truck (HEMTT).
15. Customer trucks take a standard 20 – 30 minutes to load.

Limitations

1. The model only captures the offload and distribution of cargo and does not capture any upload operations.
2. The model remains within the bounds of the JTF-PO operation from aircraft arrival to distribution of cargo.
3. The model does not consider cargo issued from the clearance yard.
4. The model does not consider passenger processing operations.

Analysis/Results

Analysis of Experimental Design

The experimental design serves the purpose to provides the user insight into the best mix of resources that will maximize the point estimators of cargo throughput in a HA/DR environment. Figure 12 identifies the 2-factorial design to use in this research. The design consists of factors, levels, responses, and scenarios. The factors are categorized into two areas, Working MOG and Distribution MOG. The Working MOG consists of the Aerial_Port_Team resources and the Distribution MOG consists of the Distribution_Section_Team resources. The levels represent the four combinations of resources that each factor will utilize in the scenarios. The responses represent the average cargo throughput to expect for each experiment. The scenarios are categorized into four experiments, CONOPS, DOE1, DOE2 and DOE3. The CONOPS scenario represents the baseline number of resources used for planning according to the JTF-PO CONOPs. The subsequent scenario, DOE1 – DOE3, represent the combination of resources each factor will utilize.

In order to check the robustness of the simulation model, a form of sensitivity analysis is performed to test the relationship between factors and responses. Sensitivity analysis is the investigation of potential changes and errors in parameter values and assumptions and there impacts on conclusions to be drawn from the model. (Pannell, 1996) For experimental purposes, the Operation UNIFIED RESPONSE time between aircraft arrival distribution is cut in half in order to double the aircraft arrival rate into the system. This procedure allows the model to run at a higher capacity and test the robustness of an optimal cargo throughput solution. Furthermore, this supports the decision maker's ability to make correct decisions about how to increase cargo throughput.

To address the investigative questions, the four experiments were modeled in order to obtain valid conclusions. The CONOPS model is the response to investigative question IQ1, DOE1 and DOE3 models are the response to investigative question IQ2, and DOE2 and DOE3 models are the response to investigative question IQ3.

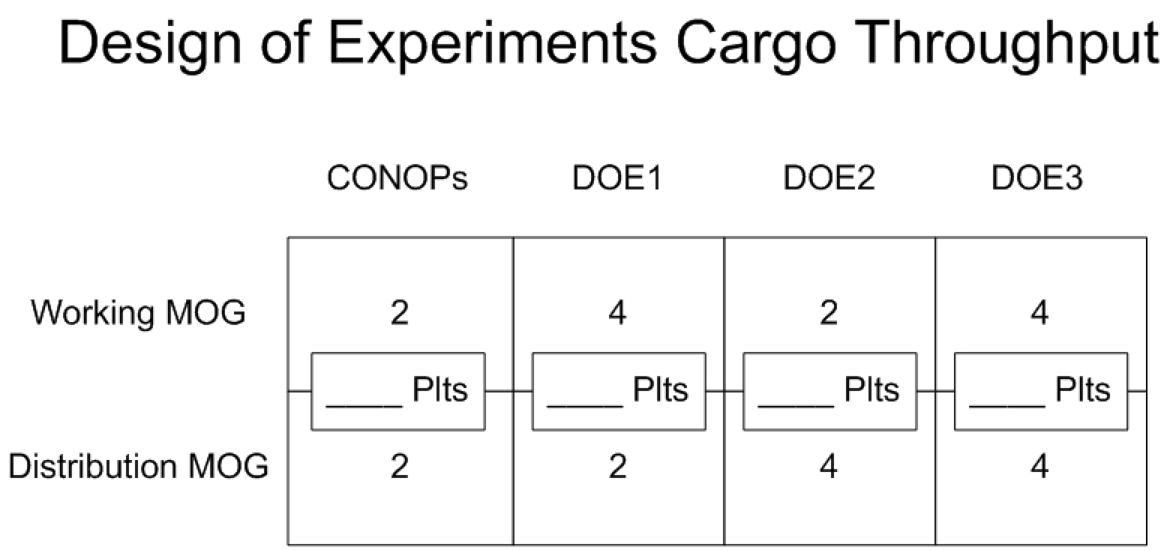

Figure 49: Design of Experiments Cargo Throughput

CONOPS Experiment:

The CONOPS experiment was designed as a baseline model, defined by the Concept of Operations for the JTF-PO, to measure against all other experimental designs.

A working MOG of two aircraft and Distribution MOG of two trucks are the two factors of interest in the model and are represented as Aerial_Port_Team and Distribution_Section_Team resources, respectively. After adjusting the values of the resources and running the model for 30 replications, the results of the experiment indicate 2,935 pallet throughputs. Additional statistics indicate a 99% utilization rate on the Aerial_Port_Team and 80% utilization rate on the Distribution_Section_Team.

DOE1 Experiment:

The DOE1 experiment was designed as the first model to determine changes in throughput by adjusting the working MOG to four and holding the Distribution MOG constant at the baseline two. After adjusting the values of the resources and running the model for 30 replications, the results of the experiment indicate an increase of 64 pallets for a throughput of 2,999 pallets. Additional statistics indicate a 47% reduction in utilization rate to 52% on the Aerial_Port_Team and a steady utilization rate of 81% on the Distribution_Section_Team.

DOE2 Experiment:

The DOE2 experiment was designed as the second model to determine changes in throughput by adjusting the Distribution MOG to four and holding the Working MOG constant at the baseline two. After adjusting the values of the resources and running the model for 30 replications, the results of the experiment indicate an increase of 87 pallets for a throughput of 3,022 pallets. Additional statistics indicate a steady utilization rate of 99% on the Aerial_Port_Team and a 49% reduction in utilization rate to 41% on the Distribution_Section_Team.

DOE3 Experiment:

The DOE3 experiment was designed as the third model to determine changes in throughput by adjusting the Distribution MOG and the Working MOG to four. After adjusting the values of the resources and running the model for 30 replications, the results of the experiment indicate an increase of 264 pallets for a throughput of 3,199 pallets. Additional statistics indicate a 47% reduction in utilization rate to 53% on the Aerial_Port_Team and a 46% reduction in utilization rate to 43% on the Distribution_Section_Team.

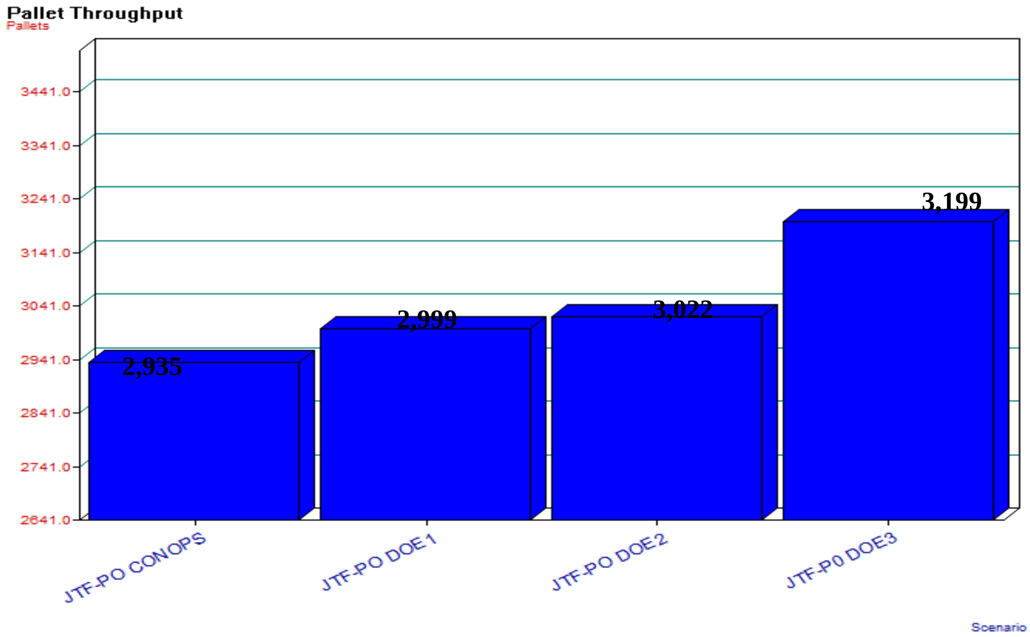

Figure 50: Pallet Issue Per Scenario

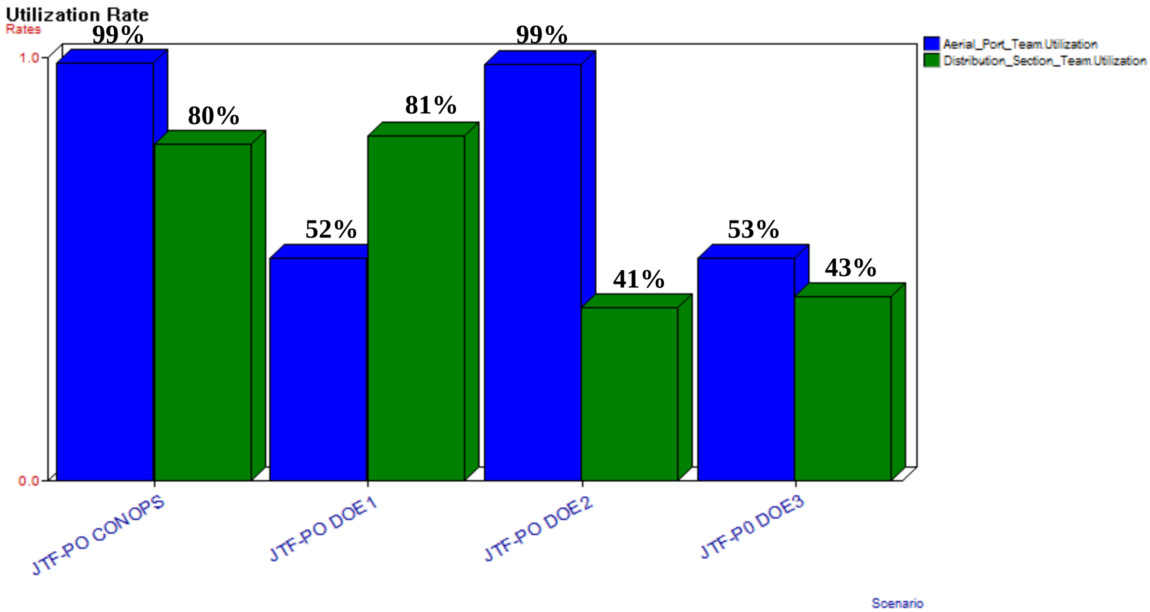

Figure 51: Resource Utilization Rate Per Scenario

Results of the Investigative Questions

IQ1: What is the throughput of inbound cargo under planned concept of operations (CONOPs) given the conditions of an HA/DR environment?

Throughput of cargo under planned CONOPs given the conditions of an HA/DR environment resulted in 2,935 pallets.

IQ2: How does inbound cargo throughput respond to a change in the working maximum on ground (MOG) resources given the conditions of an HA/DR environment?

Throughput of inbound cargo under an increase in the working MOG resources given the conditions of an HA/DR environment resulted in 2,999 pallets if Working MOG is the sole increase in resources.

IQ3: How does inbound cargo throughput respond to a change in the distribution MOG resources given the conditions of an HA/DR environment?

Throughput of inbound cargo under an increase in the distribution yard capability given the conditions of an HA/DR environment resulted in 3,022 pallets if Distribution MOG is the sole increase in resources.

Answer to the Research Question

The purpose of this research was to create a decision model through discrete-event simulation to support JTF-PO operational planning in order to predict throughput of cargo under HA/DR scenario using aircraft and cargo data collected from Operation UNIFIED RESPONSE. The result of the research question is highlighted by Figure 15. The increase of the Working MOG increases pallet throughput by 2%. The increase of Distribution MOG increases pallet throughput by 3%. The increase of both MOG resources increases pallet throughput by 8%. This suggests that an increase in Distribution MOG should be considered before an increase in Working MOG because it results in a 1% larger increase. But in order to maximize cargo throughput, an increase of both resources should be considered because they result in the largest percentage increase over all others.

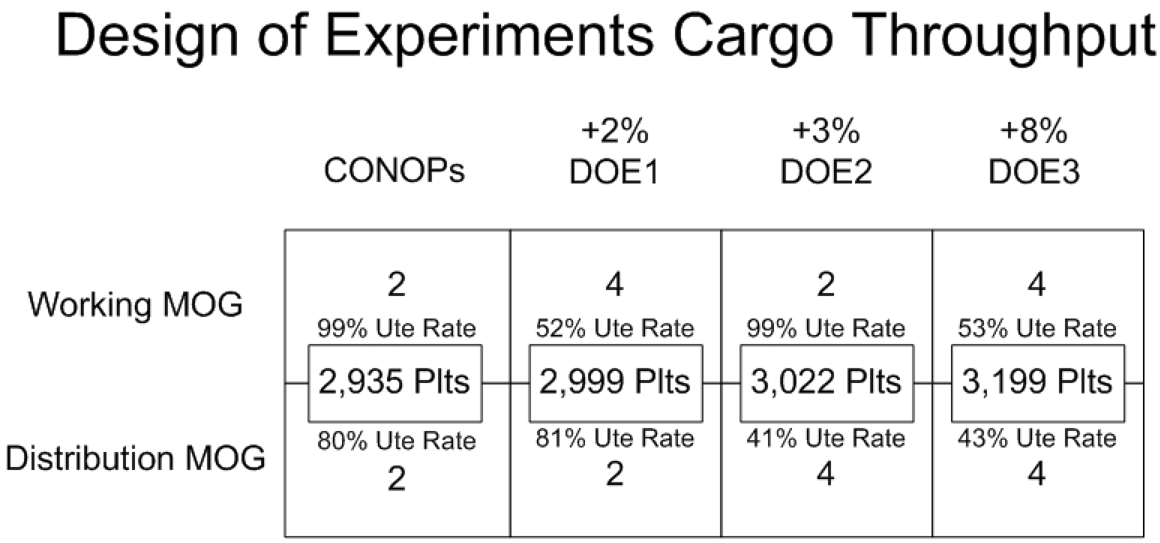

Figure 52: Design of Experiments Cargo Throughput Results

Research Conclusion

The results of the experimentation suggests that, under the research assumptions, an increase in both Working and Distribution MOG resources will result in the largest percentage increase in pallet throughput. If given the opportunity to increase resources in a JTF-PO operation in order to increase pallet throughput, Distribution MOG resources have small 1% advantage over Working MOG resources, but the largest impact should be to increase both resources.

Furthermore, this research indicates that utilization rates are extremely high for the Working MOG and Distribution MOG resources under the CONOPS scenario. By doubling the capacity of the Working MOG, the utilization rates are cut by 47% and doubling the capacity of the Distribution MOG, the utilization rates are reduced by 39%. If given the opportunity to increase resources in a JTF-PO operation in order to reduce utilization rates, Working MOG resources have an advantage over Distribution MOG resources and should be considered first. However, taken together with pallet throughput, an increase in both resources results in increased pallet throughput and decreased resource utilization rates. The result of less utilization in the resources would free them up and allow JTF-PO leadership the ability to employ them in areas that may require additional assistance. Increasing both Working and Distribution MOG resources should be the focus of decision makers when it comes to maximizing cargo throughput and reducing resource utilization.

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Vita

Captain Ryan S. Fisher is a Logistics Readiness officer in the United States Air Force. He enlisted active duty Air Force August 1998 and entered the Community College of the Air Force where he earned Associate of Applied Science degrees in Transportation and Instructor of Technology and Military Science in 2005. Furthermore, he entered undergraduate studies at Embry Riddle Aeronautical University, Worldwide Campus where he graduated with a Bachelor of Science degree in Professional Aeronautics with minors in Logistics and Management in 2007. He was commissioned through Officer Training School August 2007.

His first assignment was to Ramstein Air Base, Germany assigned to the 86th Air Mobility Squadron where he performed the duties of Air Transportation Specialist from December 1998 to July 2004. While stationed there, he deployed on numerous occasions to establish air bases in austere locations for Operations ALLIED FORCE, ATLAS RESPONSE, ENDURING FREEDOM and IRAQI FREEDOM. His next assignment was to Fort Dix, New Jersey assigned to the United States Air Force Expeditionary Center where he performed duties of Course Director of the Joint Inspection Instructor Qualification course from August 2004 to May 2007. While stationed there, he performed 1,085 hours of Community College of the Air Force instruction and conducted two instructional system development course rewrites. Capt Fisher was next sent to Officer Training School with a follow-on to McGuire Air Force Base, New Jersey to be assigned to the 817th Global Mobility Squadron where he performed duties as the Assistant Director of Operations from August 2007 to August 2010. While stationed there, he deployed in response to the 7.0 magnitude earthquake that devastated Port-au-Prince, Haiti to establish distribution operations and maximize the throughput of humanitarian assistance cargo.

In September 2010, he entered the Graduate School of Engineering and Management, Air Force Institute of Technology. Upon graduating, he will be assigned to the 6th Special Operations Squadron Hurlburt Air Field, Florida.

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13. SUPPLEMENTARY NOTES

14. ABSTRACT: Currently, no capability exists to simulate and measure a Joint Task Force-Port Opening (JTF-PO) operation in a safe, cost-effective manner in order to predict cargo throughput based on the availability of resources. The purpose of this research is to create a decision model through the use of Arena® simulation software to provide United States Transportation Command (USTRANSCOM) decision makers the ability to predict cargo throughput under a Humanitarian Assistance/Disaster Response (HA/DR) scenario. The data used in the construction of this simulation was taken from the JTF-PO involvement in Operation UNIFIED RESPONSE, Port-au-Prince, Haiti 2010. This research uses a design of experiments approach to statistically plan and measure the throughput of cargo based on the adjustment of working and distribution maximum on ground (MOG) resources. The resulting simulation model provides decision makers the ability to allocate multiple JTF-PO resource quantities to determine potential bottlenecks in cargo throughput in order to plan for future operations.

15. SUBJECT TERMS: Humanitarian Assistance, Disaster Response, Multi-Modal, Distribution Management, Cargo Throughput, Discrete-Event Simulation, Arena® Simulation, Joint Task Force-Port Opening, Decision Model, Operation UNIFIED RESPONSE, Contingency Response Group, Rapid Port Opening Element

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